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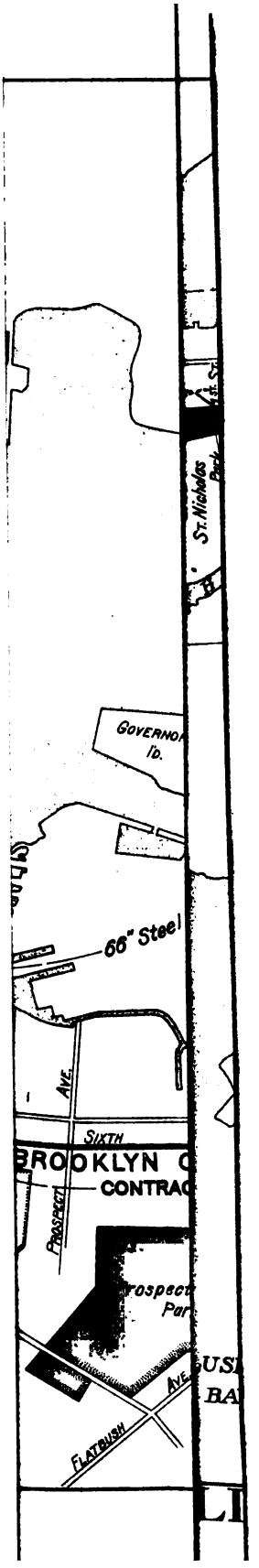
St. Nicholas Park
66" Steel
SIXTH
AVE.
PROSPECT
FLATBUSH

BOARD OF WATER SUPPLY

OF

THE CITY OF NEW YORK

CATSKILL WATER SUPPLY

Reports, Letters, Resolutions and Authorizations

ON THE

CITY TUNNEL AND THE DELIVERY OF CATSKILL WATER

TO THE

SEVERAL BOROUGHS OF THE CITY

New York City
1912

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INTRODUCTORY

The magnitude and importance of the work of the City tunnel of the Catskill aqueduct are of such a nature and the introduction of Catskill water will have so far-reaching an effect in improving the water-supply of The City that it has been deemed expedient, in order to make permanent and render readily accessible a history of the various steps and stages in the procedure which was followed preliminary to the final adoption of the plans for this tunnel, to gather into one volume the principal reports, letters, resolutions and authorizations which this procedure involved.

To the end that the various steps and movements necessitated by these preliminary proceedings may be easily coordinated and in proper sequence, their presentation is preceded by a brief account of the history of the case down to the beginning of the work of construction.

CHARLES STRAUSS
CHARLES N. CHADWICK
JOHN F. GALVIN
Commissioners, Board of Water Supply

April 15, 1912

THE CITY TUNNEL OF THE CATSKILL WATER SUPPLY AND THE DELIVERY OF WATER TO THE SEVERAL BOROUGHS OF THE CITY

Under the authority of Chapter 724 of the Laws of 1905 as from time to time amended, the Board of Water Supply has, since the date of its creation in June, 1905, proceeded with the various questions involved in the obtaining and delivering to the City of a supply of pure and wholesome water.

On October 9, 1905, the Board of Water Supply presented to the Board of Estimate and Apportionment a report covering a plan for obtaining a supply of not less than 500,000,000 gallons per day from the watersheds of the Esopus, Schoharie, Rondout and Catskill creeks, said watersheds being situated almost wholly in the counties of Ulster, Greene and Schoharie. This plan provided for the delivery of the stated quantity of water into the Hill View reservoir, located in the City of Yonkers about ½ mile north of the limits of The City of New York. This original plan of October 9, 1905 provided, however, only for the delivery of 120,000,000 gallons per day to the Boroughs of Brooklyn and Richmond. The report accompanying this plan stated that "The main distributing lines from the Hill View reservoir to the Boroughs of Manhattan, Queens and The Bronx, are matters for later consideration."

The general plan above referred to was, by resolution, approved by the Board of Estimate and Apportionment on October 27, 1905, and thereafter, pursuant to statute, application was made to the State Water Supply Commission for approval. With certain minor modifications, the State Water Supply Commission handed down its approval on May 14, 1906.

The Board of Water Supply having in mind the necessity for providing a comprehensive plan for the delivery of the Catskill water to each of the several boroughs of The City, thereafter continued its studies of this question. Two general plans for attaining the desired result presented themselves: First, the use of metal pipes laid in the usual manner through the City streets; second, a tunnel deep in the rock from which connections would be made to the distribution system through the shafts which of necessity would be required in its construction. To use metal pipes for the delivery

of this water would have required as many as 16 pipes, each 66 inches in diameter, and would have resulted in crowding many streets already badly encumbered with subsurface structures, pipes and conduits of various kinds. Such pipes might even interfere with future subway development along the main avenues of Manhattan.

The plan for a pressure tunnel deep in the rock and far below the level in the streets generally used for subsurface structures presented many advantages and, after comprehensive investigations and borings had been made, it was shown to be perfectly feasible. The principal results of the borings and geological investigations are set forth in a report by the geological expert (see page 115). This report has been revised and includes all information to date.

Among the various advantages possessed by the deep tunnel there may be briefly mentioned the following:

(1) Smaller first cost.

(2) Smaller annual charges for sinking fund, depreciation charges, repairs and maintenance.

(3) Non-interference with street surface structures during construction and use of the subsurface for subways, sewers and other structures.

(4) A minimum of depreciation and therefore a minimum of repairs with their resultant interference with the surface of the streets.

(5) Interference with service because of breaks reduced to a minimum.

(6) Practically no disturbance to streets during construction.

(7) The possibility of delivering at any point along the line of the tunnel a quantity of water greater than could be delivered by any other means, this feature having particular relation to the requirements during a great fire.

(8) Adequate cross-connection of all present distribution systems so that the main supply of any system could be temporarily put out of service and its territory supplied through the feeders of other systems.

As the result of the studies and investigations, the department engineer in immediate charge of these investigations in his report of October 1, 1909, to the Chief Engineer, sum-

marized his conclusions substantially as above and estimated the cost, including the reservoir in Richmond, at $24,650,000. (See page 22.)

The Chief Engineer of the Board of Water Supply on November 1, 1909, recommended to the Board the adoption of the deep tunnel plan, stating among other reasons that this type of construction would be the most permanent, that it would deliver the water under a greater head and that its execution would result in a minimum of interference with both present and future subsurface structures and public travel. (See page 25.) This report of the Chief Engineer was concurred in by the three consulting engineers of the Board.

The Board of Water Supply under date of November 15, 1909, addressed a communication to the Board of Estimate and Apportionment, submitting the plan for a pressure tunnel from the Hill View reservoir, beneath the Boroughs of The Bronx and Manhattan, to the Borough of Brooklyn, with lines of metal pipes to the Boroughs of Queens and Richmond. (See page 29.) The Board of Estimate and Apportionment, by resolution, then appointed December 3, 1909, as a date for a public hearing on this plan. (See page 30.) At this public hearing the Board of Estimate and Apportionment appointed a committee consisting of an engineer to be designated by the Board of Water Supply, the Chief Engineer of the Board of Estimate and Apportionment, the Chief Engineer of the Department of Finance, and the Hon. Lindon Bates, Jr., said committee being instructed to consider the proposed plan for the pressure tunnel and to report back to the Board at its meeting of December 10, 1909. (See page 31.)

Under dates of December 6 and December 8, 1909, the Chief Engineer of the Department of Water Supply, Gas and Electricity, and the Chief Engineer of that department for the Borough of Brooklyn, addressed letters to the Chief Engineer of the Board of Water Supply and favored the pressure tunnel plan for the delivery of the Catskill water. (See pages 32 and 33.)

At the meeting of the Board of Estimate and Apportionment on December 10, 1909, the committee appointed on December 3 reported as then directed. The majority report of the committee (page 35) endorsed the plan of the Board of Water Supply, and the Hon. Lindon Bates, Jr., submitted a

minority report. (See page 41.) This minority report, while criticizing the general plan, offered no suggestions for an alternative. Thereupon the Board of Estimate and Apportionment by resolution (page 43) approved the plan of the Board of Water Supply for the deep pressure tunnel.

Immediately on the approval of this plan by the Board of Estimate and Apportionment, as required by statute, petition was made for its approval to the State Water Supply Commission. (See pages 45 and 47.) On December 16, 1909, the State Water Supply Commission gave public notice of the filing of the plan for the pressure tunnel and fixed January 12, 1910, as the date for a public hearing in this matter. (See page 55.)

The Board of Estimate and Apportionment at its meeting of January 7, 1910, adopted a resolution requesting the State Water Supply Commission to defer final action upon any projected extensions or modifications of New York's water supply system (page 57). The matter then rested until March 4, on which day the Board of Estimate and Apportionment adopted a resolution calling for the appointment of three of its members, with instructions to examine into the engineering feasibility of the proposed pressure tunnel and to report thereon (page 59). In compliance with this resolution, the Mayor appointed as members of this committee the President of the Board of Aldermen, the Comptroller and the President of the Borough of Manhattan.

The committee of the Board of Estimate and Apportionment retained as expert advisers two engineers and a geologist. These advisers reported (page 60) in favor of the plan of the Board of Water Supply and concluded their report in the following words:

"We have been greatly pleased—some of us have been agreeably surprised—at the extensive and able study that this project of a Manhattan pressure tunnel has already received. Besides replying to the specific questions put to us as we have done, we desire again to say that, whether viewed from the point of first cost, maintenance or of future cost, our opinion is that The City of New York will do well to direct the immediate construction of the proposed Manhattan pressure tunnel, for purposes of distributing the Catskill water-supply to the five boroughs."

Thereupon the committee of the Board of Estimate and Apportionment, under date of June 27, 1910, reported to the Board at its meeting of July 1, 1910 (page 103). The following quotation is made from the report of this committee:

" In conclusion, your Committee is impressed with the fact that in scientific authority, in the reliability of experienced engineers and contractors, in careful and unprejudiced analysis, and in ordinary common sense, the weight of the arguments we have received is overwhelmingly in favor of the soundness and economy of the plan of the Board of Water Supply, and we would recommend that the Board approve of the plan and profile of the Board of Water Supply dated November 15, 1909, that it direct the Comptroller to issue corporate stock of The City of New York to an amount not exceeding $25,000,000 to meet the expense of carrying out the plan, that the resolution of this Board of January 7, 1910, requesting the State Water Supply Commission to suspend action on the said plans, be rescinded, and that the State Water Supply Commission be notified of this action. A resolution to this effect is herewith submitted."

The Board of Estimate and Apportionment then, on July 1, 1910, adopted a resolution approving and authorizing the plan of the Board of Water Supply for the deep pressure tunnel and directing the Comptroller to issue bonds in an amount not exceeding $25,000,000 for the uses and purposes of the Board of Water Supply. (See page 108.) This resolution also rescinded that of January 9, 1910, which requested the State Water Supply Commission to defer final action.

The way now being clear, the State Water Supply Commission, after public hearings on July 13 and 14 and after careful study, decided that the proposed plan was wise, feasible and economical. It therefore, on October 20, 1910, granted the petition and approved the plan (page 109) for the following reasons:

(1) That the plans were justified by public necessity.

(2) That the plans were just and equitable to other municipalities and civil divisions of the state.

(3) That the plans made just and equitable provisions for the determination and payment of any and all damages to persons and property.

In the meantime studies and designs leading to the preparation of contract specifications and drawings had progressed so far that it was possible to advertise four contracts for the tunnel on December 8, 1910. The advertisements were, however, recalled on December 13, 1910, and it was not until April 13, 1911, that the approval of the Corporation Counsel was received and the contracts finally advertised. Bids were opened May 16, 1911, and on May 26 and June 5 the four contracts, covering the tunnel portion and totaling $19,100,000, were awarded to the lowest bidders. (See canvasses of bids, page 114).

The work to be done comprises a circular tunnel in solid rock reducing in diameter from 15 feet to 14, 13, 12 and 11 feet along the route from the Hill View reservoir through the Boroughs of The Bronx and Manhattan to two terminal shafts in Brooklyn, from which 66-inch steel pipes, reducing to 48-inch cast-iron pipe-lines will extend into Queens and also into Richmond. Two 36-inch cast-iron pipes, resting on the harbor bottom, will cross the Narrows to the Silver Lake reservoir of 400,000,000 gallons capacity on Staten Island. The total length of this delivery system is over 34 miles. The detailed location is shown on map entitled " Catskill Aqueduct, City Tunnel and Pipe-Lines."

The tunnel will be at depths from 200 to 750 feet below the street surface, thus avoiding interference with street traffic, buildings, subways, sewers and pipes, and providing a substantial rock cover to withstand the bursting pressure, and will be constructed from 24 shafts spaced at distances of about 4,000 feet apart, located in parks and other places where little interference with traffic will result. Through these shafts, also, the water will be delivered by means of suitable connections into the existing water-mains. All of the tunnels and shafts will be lined with concrete. The estimated cost of this entire distribution system to all of the boroughs, including the tunnel, the pipe-lines and the Silver Lake reservoir, is $25,000,000, an increase of $15,000,000 over the amount included in the original plan, which provided only for the delivery of water to the Boroughs of Brooklyn and Richmond.

Up to August 1, 1912, 20 of the 24 shafts of the pressure tunnel had been sunk to their final depth, and work on the remaining 4 was well advanced. To this date over three miles of the tunnel have also been driven.

October 1, 1909.

Mr. J. WALDO SMITH,
Chief Engineer.

DEAR SIR:

In accordance with your verbal instructions, I beg to report on the type and general location of conduits to be adopted for the delivery of the Catskill Mountain water to the various boroughs, this report embodying the results of the investigations made during the past year, corrected to October 1, 1909.

To deliver the Catskill supply from Hill View reservoir to the five boroughs, one or more conduits must be built, as the main pipe-lines of the present distribution systems are barely sufficient to deliver the amount of water required at present and cannot carry any portion of the new supply.

To carry this supply either metal pipe or rock tunnels must be adopted, as the pressures are too great to be withstood by reinforced concrete pipes. The pressure tunnel system has the following advantages over metal pipes:

(1) Lower first cost.

(2) Lower annual charges for interest, sinking fund for redemption of bonds, depreciation charges, repairs and maintenance.

(3) Non-interference with street surface during construction and with use of subsurface for subways, sewers and other structures.

(4) No deterioration, and therefore, no repairs with resultant interference with surface and tearing up of streets.

(5) Interference with use because of breaks, reduced to a minimum.

(6) Practically no disturbance to streets during construction.

(7) Possibility of delivering along any point on the tunnel line a quantity of water greater than could be used in checking any threatened conflagration.

(8) Adequate cross-connection of all distribution systems, so that any system could be temporarily put out of service and its territory supplied by other systems.

The conduit system recommended consists of a single pressure tunnel from Hill View reservoir, passing under the Bor-

ough of The Bronx at an elevation of about 30 to 40 feet below tide-water, dropping at the Harlem river to a depth of about 350 feet, and continuing at this depth until Manhattan valley is passed, rising then to an elevation of about —100 and continuing with a slightly descending grade to the east side of Manhattan, where the invert is dropped to an elevation of —600 to avoid weak rock which is found near the surface, the crossing into Brooklyn being at a depth of about 250 feet below the East river, and the tunnel terminating at about Lafayette and Flatbush avenues. Pipe-lines from 66 to 36 inches in diameter are to be run to the Boroughs of Queens and Richmond.

At each shaft, that is about every 4,000 feet, connections are to be made to the distribution system by means of pressure-regulating and control valves so that the water can be delivered into the pipes at either full or reduced pressure, as may be found advisable.

With the exception of a few hundred feet at the northerly end, the tunnel is to be 15 feet in diameter as far south as 135th street, or the point where the present Croton tunnel terminates, thus making it practical to put out of service temporarily the Croton tunnel and deliver the water through the proposed Catskill tunnel. Between 135th and 40th streets the diameter will be 14 feet; between 40th and 24th streets 13 feet; between 24th and Delancey streets 12 feet; and from Delancey street to the terminal in Brooklyn 11 feet. The pipe-lines are to start as 66-inch steel pipes and reduce to 48-inch cast-iron pipes for the line to the Borough of Queens, and to 48-inch cast-iron pipes for the line to the Borough of Richmond, a 36-inch submerged pipe being used for the Narrows crossing with a 48-inch connection to the Silver Lake reservoir.

The combined tunnel and pipe-line system is shown on Sheet 2, Acc. 15492, and the pipe-line system on Sheet 3, Acc. 15493.

The proposed pressure tunnel is to be of equal capacity to the aqueduct now being constructed to carry the supply from the Catskill mountains to Hill View reservoir, and by increasing the loss of head, a much greater quantity can be delivered. The tunnel is to be located through the Boroughs of The Bronx and Manhattan and into Brooklyn, and the outlets are to be

of ample capacity to serve any one of the boroughs or such portion thereof as may be deemed advisable.

With such large conduit capacity and comparatively small increased frictional head resulting from increased velocity, it is unnecessary to provide equalizing reservoirs in the various boroughs with the exception of the Borough of Richmond, where a reservoir is provided both to equalize the pressure and safeguard the supply, this borough being dependent upon one or more submerged pipe-lines which would require time to repair and which are more liable to failure than lines laid under streets.

As the conduit system is kept mainly within street and park limits, there will only be about 1,700 feet of private right-of-way to be acquired, and all shafts except two are to be on City property.

If work is prosecuted actively and continuously, about four years will probably be required for construction.

The estimated costs of the combined tunnel and pipe-line system and of the pipe-line system, in both cases omitting the reservoir in Richmond, are as follows:

System	Construction Cost	Cost Reduced to Present Worth Basis
Tunnel and pipe-line	$23,400,000	$22,400,000
All pipe-line	47,100,000	36,200,000

GENERAL CONDITIONS GOVERNING DELIVERY OF CATSKILL WATER

Catskill water, supplemented by that obtained from the Croton, Bronx and Byram watersheds, is the logical supply for the Boroughs of Manhattan and The Bronx. For the Boroughs of Brooklyn, Queens and Richmond the source of additional supply will depend partly upon the action taken in relation to the Suffolk County watershed. Even if this watershed is made available, a portion of the Catskill supply should be delivered to Brooklyn, Queens and Richmond. Cross-connection of all water-supply systems of the City is necessary to utilize to the best advantage the storage in the various watersheds, to give flexibility in distribution and to

safeguard against serious interruption in any supply. With such a connection the Long Island water might be used as an emergency supply for Manhattan, or the Croton water for Brooklyn.

The comparatively high elevation at which the Catskill water will be delivered, makes it available for the territory at present served by the Williamsbridge, Bronx high, and Manhattan main and upper high services, thus eliminating the expense of the pumping-stations connected with these services. The balance of the supply from the Catskill works can be used in The Bronx and Manhattan, where the Croton supply does not give adequate pressure and where house pumps are used, in the higher services of the Boroughs of Brooklyn and Queens, and in Richmond. This distribution of the water would result in saving nearly $2,000,000 annually which is expended for maintaining and operating public and private pumping-plants.

LOCATION OF DELIVERY CONDUITS

Conduit lines should pass through or terminate in those districts where the water is to be used, the location depending on the consumption and conditions affecting construction.

The water consumption of the Boroughs of Richmond, Queens and The Bronx approximates 60,000,000 gallons daily, while in Manhattan and Brooklyn it is over 450,000,000 gallons daily. Manhattan and Brooklyn will, for many years to come, require the greater part of the water-supply, only a small percentage being used for the other boroughs. The population of Manhattan will probably cease to increase within the next 20 years, but the water consumption of that borough is not mainly due to the resident population but to use in buildings devoted to manufacturing, offices and other business purposes. The amount of water required will probably continue to increase, even after the population decreases. If large conduits are constructed from Hill View reservoir through the Boroughs of The Bronx, Manhattan and Brooklyn, and connected with the Long Island distribution system, they will traverse the territory of maximum consumption and efficiently distribute the supply. This route would be economical for a

PLATE 1

Harlem River crossing, Hole 42, 455 feet deep, which penetrated contact between limestone and schist, and furnished cores which were 1¾ inches to 3 inches in diameter; 97 per cent. of the limestone core was recovered.
Contract 38, October 13, 1909.

pressure tunnel system. Cost and difficulties of construction in the Borough of Manhattan would make the Bronx-Queens-Brooklyn route advisable for a pipe-line system to transport the water to Queens, Brooklyn and Richmond. The two routes have been investigated and tentative conduit line locations made, as shown on Sheets 2 and 3, Accs. 15492 and 15493.

The practicability of the Bronx-Manhattan-Brooklyn pressure tunnel is dependent upon the borings showing suitable ledge-rock. Professor Kemp and Dr. Berkey, the geological experts, reported before the borings were commenced that probably a satisfactory rock formation would be encountered along the proposed tunnel line. This opinion has been substantiated by the hundred or more borings made along, and in the vicinity of, the proposed line, some of the borings being about 25 feet apart where uncertain formation was expected. The location and elevation of the tunnel have been fixed by the rock condition and street and park alinement. Sound rock comparatively near the surface has been found along the entire line except under the Harlem river, Manhattan valley and the lower east side of Manhattan. Under the Harlem river the soft rock was found at the contact between the limestone and Manhattan schist to a depth of about 160 feet, or about the same as found when the New Croton tunnel was driven under the river about 1,500 feet north of the proposed crossing. At a depth of 200 feet a sound contact was found and the tunnel is to be nearly 200 feet below this sound contact. Under Manhattan valley, schist was found about 200 feet below the surface; but six holes put down within a space of two blocks did not indicate any disintegration of the rock. Under the lower east side the borings made have shown sound rock to be from 300 to 400 feet below the surface, but no indication that sound rock cannot be found at reasonable depths for tunneling. The deep rock valley is narrow, so that the shafts on each side could be sunk in sound Fordham gneiss which is near the surface, and the tunnel would cut the rock 200 or more feet below the sound rock floor. Under the East river and in Brooklyn the most impervious and durable rock along the entire line has been found. The rock floor in Brooklyn probably slopes downward to the southeast preventing carrying the tunnel beyond the proposed terminal at Lafayette

and Flatbush avenues. It also would not be economical beyond this point, due to the divergence of the necessary lines of distribution and the comparatively small quantities to be carried.

SIZE OF CONDUITS

The magnitude of the Catskill supply necessitates the use of larger conduits than those normally employed for delivery purposes, and it is advisable to adopt conduits of the maximum diameter that can be laid in City streets without seriously interfering with or endangering other structures. In New York City any large pipe-lines will interfere with sewer pipes, electric ducts, water-mains and gas-mains, and after a certain diameter is reached, the sewer system would have to be remodeled and grades changed. While these obstacles are important, the most important factor is the construction of subways. Manhattan island will, at some time in the future, undoubtedly have subways in practically all the north and south avenues, while The Bronx will also have many of its streets occupied by subway structures. The danger of damage to life and property increases with the size of pipe, and the usual practice limits the diameter of street mains to 48 inches. It is not prudent to increase the diameter of steel pipes beyond 60 to 66 inches. The sewer grades in The Bronx make it impracticable to lay mains larger than 66 inches in diameter without replacing the sewers, and this size has been adopted as the maximum to be considered. For pressure tunnels, the size is practically unlimited, as the conduit would be entirely in bed-rock and at an elevation below any present or proposed subsurface structure. The only interference with subsurface structures would be at shaft sites, and as these would be located approximately 4,000 feet apart, and in parks or side streets, they would not be serious obstructions.

POSSIBLE TYPES OF CONDUIT CONSTRUCTION

The main factors in determining the type of conduits are: safety from failure, permanence, cost, interference with surface and subsurface structures during construction and after completion, interference with traffic during construction, and freedom from disturbance by future construction. The types

Shot drill at southwest corner of 123d street and Morningside avenue working under Contract 38. This drill penetrated 320 feet and furnished 3-inch cores. October 13, 1909.

to be considered would be reinforced concrete, cast-iron or steel pipes, or lined tunnels driven in the ledge-rock. The use of reinforced concrete would be limited to sections where the pressure would not exceed, approximately, 30 pounds, and therefore this type of construction would not be suitable to meet the conditions in Greater New York. From the viewpoint of safety from failure, cast iron is not satisfactory, owing to its unreliability, especially for large pipes under heavy pressure. Steel would be reliable until deterioration due to corrosion had weakened the metal sufficiently to cause fracture. A pressure tunnel constructed in the rock at a grade well below that of other subsurface structures would be safe from failure, and the only possibility of a break interfering with the supply from the tunnel would be at the points of connection, which would be at each shaft site. For safety in operation, the type of conduit to be adopted would be pressure tunnel. This type would be the only permanent one, as corrosion and electrolysis make indefinite and uncertain the life of metal pipes and at some time necessitate their replacement. In comparing relative economy of conduits, it is necessary to consider their capacity with the same hydraulic gradient and their cost per unit of length. This comparison for cast iron, steel and pressure tunnel would be as follows:

Conduit	Size	Nominal Capacity Million Gallons Daily	Construction Cost per Foot	Resultant Cost per Foot per Million Gallons Daily Capacity
Cast iron	48 inches	19	$35.00	$1.84
Steel	66 inches	32	40.00	1.25
Pressure tunnel	15 feet	500	250.00	.50

There can be no question as to the economy of pressure tunnels over pipe-lines where large quantities of water are to be delivered and rock conditions are favorable. Deferment in installation of pipes would reduce somewhat the apparent difference in cost, but only slightly. If the maintenance and annual charge basis be used for comparison instead of the construction cost, the difference would be still more striking.

Interference with present and prospective structures, both above and below the surface of the street, is reduced to a minimum by the construction of a tunnel, while a large num-

ber of pipe-lines would prevent the building of subways and other subsurface structures in streets where the pipe-lines were installed. A pressure tunnel has a manifest advantage over pipe-lines during construction, in the slight amount of inconvenience caused to traffic and business, due to the work being carried on below the surface. This advantage might not be important if only one pipe-line were to be laid, but where approximately 16 pipes, 66 inches in diameter, or 30 pipes 48 inches in diameter, would be required instead of one pressure conduit, its value is manifest. The pipe-lines would have a slight advantage from a distribution view-point, in reducing the mileage of smaller connecting mains and in splitting up the conduits into a large number of parts and thus making it possible for one or more units to be put out of service without seriously affecting the whole system. It is hardly conceivable that the tunnel itself can fail, and at the shafts, special safeguards will eliminate practically all chance of having to shut down the tunnel due to a break in any appurtenance. On account of their comparatively short life, the pipe-lines would require the tearing up of streets at intervals of about 35 years, whereas the tunnel would last indefinitely. There would also be a period of years immediately preceding the replacement of pipe-lines when breaks would be comparatively frequent, due to the difficulty in determining the actual condition of the mains. Serious damage to property, and possibly to life, might result from such failures of the pipes.

Where the total amount of water to be carried exceeds 150,000,000 gallons daily, a pressure tunnel is both economical and desirable for New York City conditions, if the geological formation permits of such construction.

ECONOMIC SIZE OF PRESSURE TUNNEL

In determining the probable diameter of pressure tunnel that will give the most economical results, it is necessary to consider the relative cost of tunnels of different diameter, and the time when the maximum capacity of a conduit of any given size will be utilized by the increase in consumption. The studies made have been based on the estimated cost of tunnels, on the capacity with a gradient of three feet per mile, and on the probable consumption in the various boroughs.

Shot drill furnishing 1¾-inch core at 110th street and Morningside avenue. Contract 38. October 13, 1909.

The theoretical present worth of the construction costs of tunnels from 12 feet to 16 feet 6 inches in diameter have been computed, as an aid in fixing the economic size of a single tunnel. In making these computations, it has been estimated that when the consumption equals the nominal carrying capacity of the tunnel, after allowing 15 per cent. for hourly fluctuation in flow, a second tunnel of equal size would be constructed. The results of these studies show that there is little difference in economy when the diameter exceeds 14 feet 6 inches. The factors involved in the question of size are not sufficiently well defined to permit of an accurate solution of the problem, and a tunnel of any diameter from 14 feet 6 inches to 16 feet 6 inches might be chosen with little, if any, difference in the ultimate cost to The City.

It is proposed to carry the tunnel of the 15-foot size under the Harlem river and south to 135th street, where connection will be made with the Croton gate-house, the 14-foot size being carried to 40th street, where the convergence of important railway lines indicates a concentration of large, high buildings, requiring many million gallons of water per day. The 13-foot tunnel is to be carried to 24th street, where connection will be made with numerous large distribution pipes. The 12-foot tunnel terminates under Delancey street near the Bowery, and an 11-foot tunnel has been adopted to cross under the lower east side of Manhattan, to supply Brooklyn. A tunnel of this size will carry approximately 290,000,000 gallons daily, and the cost would be about 8.5 per cent. greater than that for a 10-foot tunnel, whereas the carrying capacity would be about 26 per cent. greater. It is therefore practical to obtain the larger conduit capacity at a comparatively slight increased expenditure. Furthermore, with the additional conduit capacity under the East river, it would be practicable to draw, from time to time, more heavily on the gravity sources and reduce the amount pumped from Long Island, thereby saving the cost of pumping, and also, in an emergency, deliver all the water required for Brooklyn through the tunnel. The economic size cannot be mathematically determined, and the size to be adopted is mainly a question of judgment.

In the extension of the aqueduct south of Hill View reservoir, it is possible to deliver an additional amount of water

over and above the assumed capacity of the aqueduct, by increasing the loss in head. It is probable that the pressure tunnel below Hill View reservoir will at times be called upon to deliver a much greater quantity of water than the normal capacity of the Catskill aqueduct. It will therefore be advisable to construct this aqueduct of as large size as can economically be adopted, and thus defer the installation of a second tunnel for many years. To illustrate the increased loss in pressure that would be due to the adoption of a smaller tunnel than the one proposed, estimates have been made which show that a tunnel starting at 13 feet and reducing to 10 feet in diameter would increase the loss in head by 75 per cent., while a tunnel starting at 12 feet and reducing to 9 feet in diameter would increase it by 150 per cent. The corresponding decreases in cost would be 10 per cent. and 15 per cent. The loss in head would show still greater proportional difference if the quantity to be carried was materially increased. The proposed tunnel gives practically the same loss in head as the Catskill aqueduct would give for an equal distance.

EFFECT OF PROPOSED SYSTEM ON SYSTEM FOR BROOKLYN AND RICHMOND OUTLINED IN REPORT OF OCTOBER 9, 1905

In the report of 1905 an estimate was made of the cost of pipe-lines necessary to carry 100,000,000 gallons daily from Hill View reservoir to Forest park, Brooklyn, and 20,000,000 gallons daily to Richmond. This plan consisted of a single large steel pipe through The Bronx, crossing under the East river in tunnel and dividing in Queens into two mains, one running to Forest park and the other to Richmond. The estimated cost was $10,224,000.

Under this plan water would be delivered at Forest park at Elevation 180 and at Richmond at elevation of about 120, the loss in head from Hill View reservoir to Brooklyn being 110 feet and to Richmond 170 feet. Necessary reservoirs in Forest park and Richmond would add from $4,000,000 to $5,000,000 to this cost, as, due to the very high velocities in the pipe-lines, practically no additional supply could be delivered to take care of the hourly fluctuation in consumption. Of the nominal 500,000,000 gallons daily to be supplied from

Catskill sources, only conduit capacity for 120,000,000 gallons daily was provided for south of Hill View reservoir, and over three times this amount, or 380,000,000 gallons daily, had to be delivered to The Bronx, Manhattan, Queens and Brooklyn. The amounts required for each borough are estimated approximately as 80,000,000 gallons daily for The Bronx, 200,000,000 gallons daily for Manhattan, 40,000,000 gallons daily for Queens and 60,000,000 gallons daily for Brooklyn.

In designing the most economical system to handle the 380,000,000 gallons daily, it was found that by including the 120,000,000 gallons daily in a tunnel system, the water could be delivered to Brooklyn and Richmond for approximately half what it would cost under the 1905 plan, and the loss in head at the point of consumption would be reduced by about 100 feet. The system covered by the 1905 report has therefore been modified by including it in the tunnel plan.

TYPE OF CONDUIT CONSTRUCTION SUITABLE FOR THE VARIOUS BOROUGHS

The Bronx

The consumption in the Borough of The Bronx will not be of sufficient amount to materially affect the type or size of the conduit necessary to distribute the water from the Hill View reservoir. The geological conditions are favorable to the construction of a pressure tunnel. Parks, street intersections and other public property provide suitable shaft sites. It has been assumed that one 15-foot tunnel will be constructed, having a capacity of about 630,000,000 gallons daily, with a hydraulic gradient of three feet to the mile. This would be equivalent to the maximum hourly consumption with an average consumption of 500,000,000 gallons daily.

Manhattan

The arguments in favor of a pressure tunnel apply especially to the Borough of Manhattan and also to the crossings under the Harlem and East rivers.

Brooklyn

The amount of water to be carried to any section of Brooklyn is hardly sufficient to make a pressure tunnel economical

beyond the river front. Furthermore, the geological conditions preclude the possibility of economically constructing a tunnel for any considerable distance under Brooklyn, and it is therefore proposed to carry the tunnel on the Brooklyn side for only a few thousand feet from the river front. Steel or cast-iron pipes would be used to carry the necessary supply for Staten Island through Brooklyn to the Narrows, connections being made from this line to the high service sections in the vicinity of Prospect park.

Queens

Comparatively small mains will be required for the Borough of Queens, and these will be either of steel or cast iron, as detailed study may indicate to be advisable. It will probably not be necessary to lay mains larger than 48 inches in diameter for this service.

Richmond

The supply for this borough must be carried under the Narrows and owing to the excessive depth to rock, it will be advisable to lay some form of submerged pipe-line. There are no special difficulties to be anticipated in the construction of such a line, except the number and size of the vessels passing. There might be some danger of a break in the line, due to vessels dragging their anchors and fouling with the pipe-line, or the explosion of mines in war time destroying a section of the pipe. As the pipe would be laid 20 feet or more below the bottom of the harbor, the danger from anchors is slight.

The building of a large equalizing reservoir in Richmond will maintain the supply for several weeks and give an opportunity to repair any break in the main. One 36-inch main is proposed for the Narrows crossing, it being expected that this main would be duplicated in about 1925, as the increase in consumption by that time would warrant the construction of the second main as a safeguard, although the one main would be of sufficient capacity to deliver the required supply.

EQUALIZING RESERVOIRS

In the Borough of Brooklyn the Ridgewood reservoir affords ample capacity to meet the requirements of the low service. There is no available reservoir site for the Catskill service

PLATE 4

Closed box contains core recovered from Hole 42 at contact between limestone and schist under Harlem river. Open boxes contain 3-inch, 1¾-inch and 1-inch cores. November 12, 1909.

in Brooklyn which will deliver water at a sufficiently high elevation to feed both the present Mt. Prospect high and low services. The Mt. Prospect tower could be used as a relief valve on this new service, which would supply the territory fed by the present Mt. Prospect services.

In the Borough of Queens, the Ridgewood reservoir would be satisfactory for the low service, and until the higher ground is much more densely populated than at present, it would not be necessary to provide a reservoir, the existing stand-pipes being sufficient for the needs of the system. When the high sections of the borough are extensively built up, it will probably be advisable to construct a reservoir of sufficient capacity to maintain an approximately uniform hydraulic gradient throughout the day, but it will be many years before this reservoir is needed.

For the Borough of Richmond, studies were made of available sites and the cost of reservoirs in Silver Lake and Clove Lake valleys was estimated. A reservoir in the Clove Lake valley would give a storage of about 900,000,000 gallons. This reservoir could only be used for an emergency supply, owing to its low elevation. On the Silver Lake site, a reservoir with a flow-line of 225 feet would have a capacity of about 400,000,000 gallons, and this reservoir would cost somewhat less than one at Clove lake. The Silver Lake reservoir could be used as an equalizing basin in connection with the Catskill supply, and its construction is therefore recommended. The estimated cost of the reservoir, including land, is $1,260,000.

TIME REQUIRED FOR CONSTRUCTION

The time necessary to complete the delivery system will be determined by the difficulties that may be encountered in driving 5,000 feet of tunnel, as this distance will represent the probable maximum distance between shaft sites. Assuming an average rate of progress of eight feet per day in each heading, or a total of 16 feet per shaft, it would require about one year to drive a section. To this must be added about 2½ years for assembling of plant, sinking shafts, concreting of tunnel, and completion of connections, thus allowing 3½ years for actual work. From six months to a year must be allowed for the collection of necessary information and preparing and

letting of contracts. The tunnel might be completed in say four years, or possibly in less time by strenuous endeavors and good fortune. It would hardly be safe, however, owing to delays from uncertain causes which cannot be predicted but which almost always occur in the prosecution of New York City work, to estimate on the completion of all portions of the tunnel within four years.

ESTIMATED COST

Estimates have been made of the cost of the combined tunnel and pipe-line system and of the pipe-line system, basing the cost for the tunnel on the bids received for similar work along the Catskill Aqueduct line, and making allowance for additional cost for handling the spoil within City limits. These estimates have been checked by comparing prices paid for a sewer tunnel in The Bronx and one just north of the City line, work on these tunnels being now under way. The estimates used herein exceed, by 10 per cent. or more, the sewer tunnel prices. The pipe work has been estimated on prices based on City contracts.

COMBINED TUNNEL AND PIPE-LINE SYSTEM

PRESSURE TUNNEL

SIZE OF TUNNEL	LENGTH MILES	COST PER MILE	TOTAL COST	
16 feet, 7 inches	0.40	$1,160,000	$460,000	
15 feet	7.31	1,030,000	7,540,000	
14 feet	4.94	950,000	4,700,000	
13 feet	0.40	870,000	350,000	
12 feet	1.36	820,000	1,120,000	
11 feet	3.24	770,000	2,500,000	
Easements, right-of-way, etc.			150,000	
2 drainage shafts			250,000	
			$17,070,000	
20 per cent. for engineering and contingencies			3,414,000	
				$20,484,000

PIPE-LINES

SIZE OF PIPE	LENGTH MILES	COST PER MILE	TOTAL COST	
66-inch steel	2.4	$164,000	$394,000	
48-inch cast iron	10.5	121,000 to 137,000	1,400,000	
36-inch cast iron	1.7	100,000	170,000	
36-inch submerged	2.0	264,000	528,000	
			$2,492,000	
15 per cent. for engineering and contingencies			374,000	
				$2,866,000
Total				$23,350,000

PIPE-LINE SYSTEM

PIPE-LINES

SIZE OF PIPE	LENGTH MILES	COST PER MILE	TOTAL COST	
66-inch steel	210.5	$164,000 to 214,000	$38,500,000	
66-inch submerged	0.3	345,000	104,000	
48-inch cast iron	3.8	137,000	521,000	
36-inch cast iron	1.7	100,000	170,000	
36-inch submerged	2.0	264,000	528,000	
			$39,823,000	
15 per cent. for engineering and contingencies			5,973,000	
				$45,796,000

PRESSURE TUNNEL

SIZE OF TUNNEL	LENGTH MILES	COST PER MILE	TOTAL COST	
10 feet	0.8	$890,000	$710,000	
8 feet	0.5	700,000	350,000	
Easements and right-of-way			50,000	
			$1,110,000	
20 per cent. for engineering and contingencies			222,000	
				$1,332,000
Total				$47,128,000

In the preceding estimates no allowance has been made for the reservoir in Richmond, which is estimated to cost, including engineering and contingencies, about $1,300,000.

After making due allowance for possible deferment of installation of pipe-lines, the present worth of the bond issues is as follows:

Combined tunnel and pipe-line system	$22,400,000
Pipe-line system	36,200,000

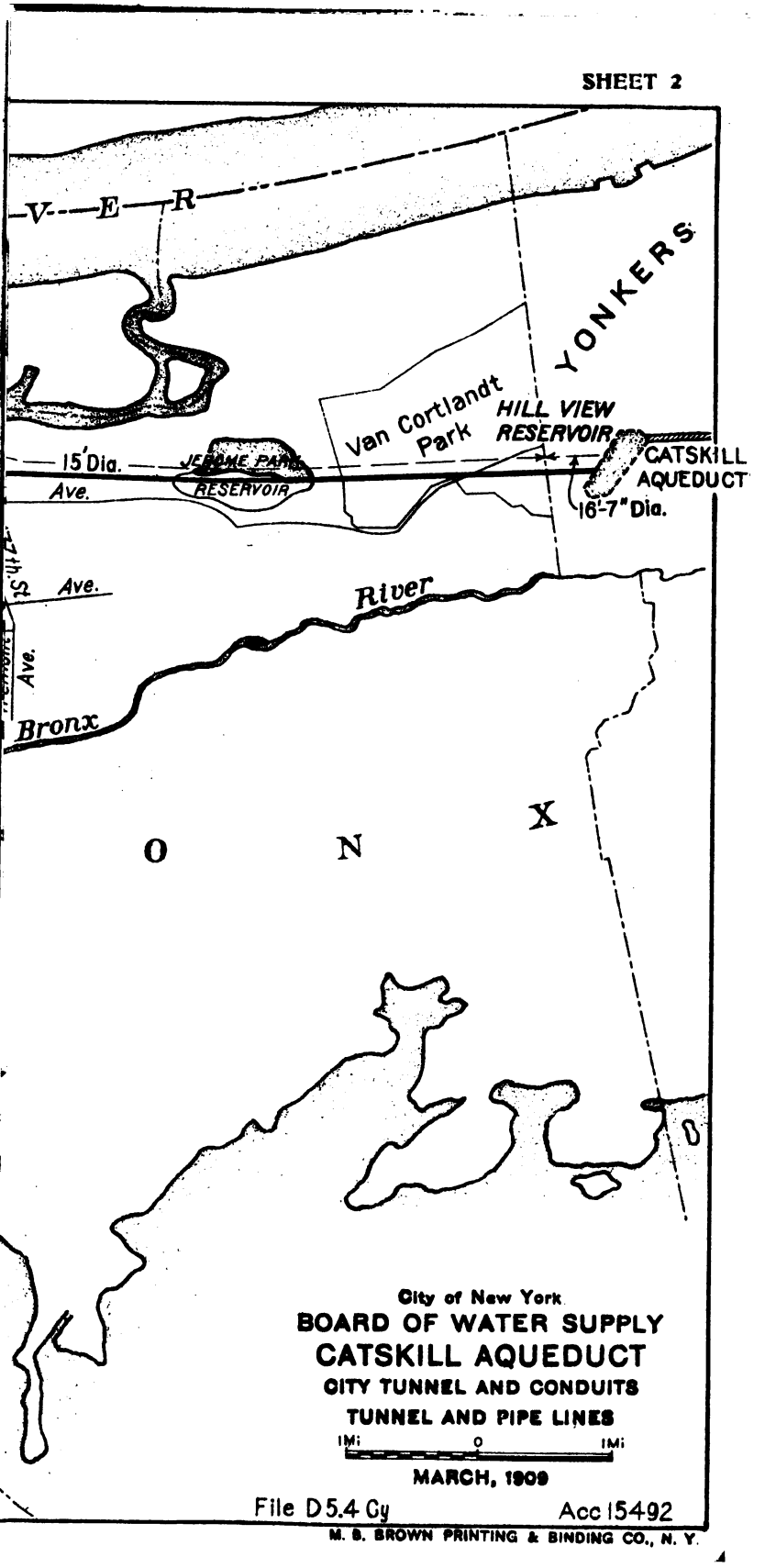
As these two systems accomplish practically the same results in delivering the water to the various boroughs, the combined tunnel and pipe-line system is the more economical.

Respectfully submitted,

WM. W. BRUSH,

Department Engineer.

SHEET 2



City of New York

BOARD OF WATER SUPPLY

CATSKILL AQUEDUCT

CITY TUNNEL AND CONDUITS

TUNNEL AND PIPE LINES

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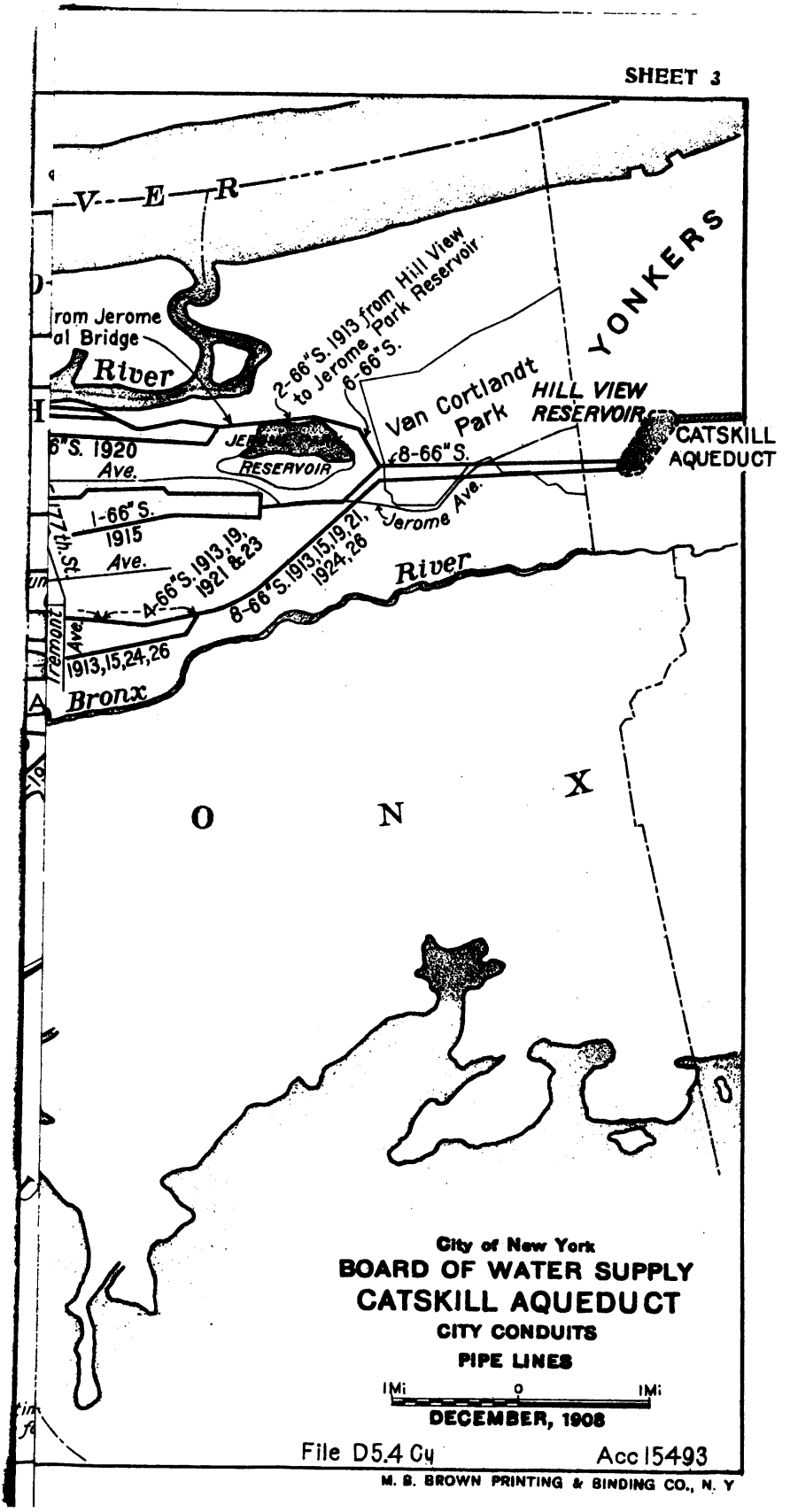
MARCH, 1909

File D 5.4 Cy Acc 15492

M. B. BROWN PRINTING & BINDING CO., N. Y.

SHEET 3



File D5.4 Cy Acc 15493

M. B. BROWN PRINTING & BINDING CO., N. Y

BOARD OF WATER SUPPLY
CITY OF NEW YORK
ENGINEERING BUREAU
299 BROADWAY

J. A. BENSEL
CHARLES N. CHADWICK
CHARLES A. SHAW
COMMISSIONERS
J. WALDO SMITH
CHIEF ENGINEER
C. L. HARRISON
DEPUTY CHIEF ENGINEER

New York, November 1, 1909.

BOARD OF WATER SUPPLY,
299 Broadway, City.

GENTLEMEN:

I transmit herewith a plan for the delivery of water to the several boroughs of The City of New York. This plan modifies that portion of the plan of October 9, 1905, approved by the Board of Estimate and Apportionment on October 27, 1905, which lies between Hill View reservoir and the Boroughs of Brooklyn, The Bronx, Queens and Richmond, so that the line now includes the Borough of Manhattan. This modification results in a shorter total length of line of about 5 miles and provides also for the delivery of more water and at approximately 100 feet greater pressure to the Boroughs of Brooklyn, Queens and Richmond, while at the same time it fully cares for the needs of the Borough of Manhattan. In these respects it is superior to the plan of 1905.

The plan submitted herewith contemplates the construction of a pressure tunnel in the ledge-rock from Hill View reservoir beneath the Borough of The Bronx, the Harlem river, the Borough of Manhattan and the East river, to a point in the Borough of Brooklyn near the East River front, where ledge-rock drops so far below the surface of the ground as to render this type of construction impracticable of further extension. From this point it is proposed to lay metal pipes through the Borough of Brooklyn to that of Queens and across the Narrows to the Borough of Richmond, where an equalizing reservoir of about 400,000,000 gallons capacity, at an elevation of

about 225 feet above tide, is proposed as the terminal of this line.

Shafts for facilitating the construction of the tunnel will be spaced from 3,000 to 5,000 feet apart throughout its length, and permanent connections to the distribution pipes in the streets will be made through them. Connections will also be made with Jerome Park reservoir and the gate-house of the Croton aqueduct at 135th street. The pipe-lines through Brooklyn to the Boroughs of Queens and Richmond will intersect practically all the present main distribution lines in that borough, and connections to them will be made at such points as may be found desirable.

The entire length of the tunnel, 17.6 miles, and the connecting pipe-lines running to Brooklyn, Queens and Richmond, a total length of 33.5 miles, including the tunnel, will, with the exception of about 3,300 feet, be located beneath or through streets, parks and other City property, so that the necessity of resorting to condemnation proceedings is almost entirely eliminated.

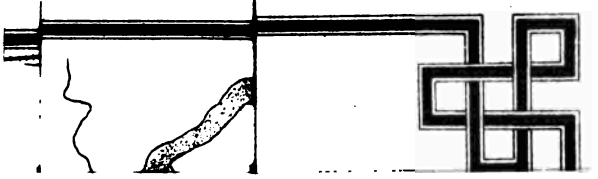
The tunnel under the East river will afford a long-desired and necessary connection between the water systems of two principal boroughs of The City and so render possible an interchangeable use, as may be necessary, of the water from the northerly mountain sources and that obtained from the sands of eastern Long Island.

The Boroughs of Manhattan and The Bronx, taken together, cover a long and relatively narrow strip of land. They obtain their water-supply from the north and, by reason of this fact, as well as that of the general north and south direction of traffic, the main streets, particularly in the Borough of Manhattan, are already well filled with water and gas-pipes, electric conduits and other structures on, above and under the surface. It is, therefore, both impracticable and undesirable that a quantity of water, as large as the 500,000,000 gallons per day to be furnished by the Catskill supply, should be brought into The City by means of metal pipes laid beneath the surface of the streets. Even in case this method were more economical, it would not be desirable to introduce possible barriers into the streets which might interfere with further extension of the subway or other necessary public uses of the streets.

The tunnel from Hill View reservoir to the Borough of

East River crossing. Drill furnishing 1-inch core working on barge at foot of Jay street, Brooklyn. Contract 38. August 12, 1909.

PLATE 5



BOARD OF WATER SUPPLY
CITY OF NEW YORK
299 BROADWAY

COMMISSIONERS
J. A. BENSEL
CHARLES N. CHADWICK
CHARLES A. SHAW
THOMAS HASSETT, SECRETARY

New York, November 15, 1909.

HON. GEORGE B. MCCLELLAN, MAYOR,
Chairman, Board of Estimate and Apportionment,
City Hall, New York City.

SIR:

The Board of Water Supply begs to submit herewith plan adopted November 15, 1909, which in part is a modification of that portion of the map approved by the Board of Estimate October 27, 1905, which provides for the conveyance of the Catskill water through the Boroughs of Brooklyn, Queens and Richmond.

The modification is recommended for the reason that a larger amount of water would be by this plan delivered to the boroughs above mentioned and under a head about 100 feet and by a route 5 miles shorter than on the plan previously approved. Through Manhattan island the plan contemplates the construction of a pressure tunnel in rock, which construction will also continue to the Boroughs of The Bronx and Brooklyn, except where the ledge-rock is at a distance below the surface too great for such construction. Connection will be made with the distribution system of the several boroughs at convenient points. The entire length of the tunnel about 17½ miles, connecting pipe-lines running to Brooklyn, Queens and Richmond, 33½ miles including tunnel, will, with the exception of about 3,300 feet of length, be located through City property, so that condemnation proceedings are almost entirely eliminated from construction in the map herewith considered.

Very truly yours,

BOARD OF WATER SUPPLY,
Per THOMAS HASSETT,
Secretary.

BOARD OF
ESTIMATE AND APPORTIONMENT
CITY OF NEW YORK
OFFICE OF THE SECRETARY
277 BROADWAY

New York, November 22, 1909.

HON. P. J. SCULLY,
City Clerk,
City Hall, New York.

SIR:

Notice is hereby given that at the meeting of the Board of Estimate and Apportionment, held on November 19, 1909, the following resolutions were adopted:

Whereas, The Board of Water Supply of The City of New York, pursuant to chapter 724 of the Laws of 1905, as amended, has submitted to the Board of Estimate and Apportionment a report and plan which bears the date of Novemver 15, 1909, and is entitled "Map and profile showing manner of delivering the water to the several boroughs"; said map being now on file in the office of the Board of Water Supply of The City of New York, 299 Broadway, New York City; now, therefore, be it

Resolved, That the 3d day of December, 1909, at 10.30 o'clock in the forenoon, at Room 16 in the City Hall, in The City of New York, be fixed as the time and place for a public hearing upon the said report and plan, and that notice be given of such public hearing by publication in the City Record, and in the newspapers designated by the Board of City Record as official City papers; and be it further

Resolved, That the Secretary of this Board be directed to give such notices as are provided for in said statute.

Respectfully,

BOARD OF ESTIMATE AND APPORTIONMENT,
Per JOSEPH HAAG,
Secretary.

BOARD OF
ESTIMATE AND APPORTIONMENT
CITY OF NEW YORK
OFFICE OF THE SECRETARY
277 BROADWAY

New York, December 3, 1909.

HON. J. A. BENSEL, COMMISSIONER,
Board of Water Supply, City of New York.

DEAR SIR:

At the meeting of this Board held on this day a Committee was appointed, to consist of an engineer to be designated by the Board of Water Supply, the Chief Engineer of the Board of Estimate and Apportionment, the Chief Engineer of the Department of Finance and Mr. Lindon Bates, Jr., to consider the proposed modification of the general plan for the development of the Catskill water supply which relates to the distribution system within the City limits, and said Committee was instructed to report back to the Board of Estimate and Apportionment by Friday, December 10, 1909.

Respectfully,

JOSEPH HAAG,
Secretary.

DEPARTMENT OF
WATER SUPPLY, GAS & ELECTRICITY
OFFICE OF CHIEF ENGINEER
13-21 PARK ROW

JOHN H. O'BRIEN
COMMISSIONER
M. F. LOUGHMAN,
DEPUTY COMMISSIONER
I. M. DE VARONA,
CHIEF ENGINEER

City of New York, December 6, 1909.

MR. J. WALDO SMITH,
Chief Engineer, Board of Water Supply,
299 Broadway, New York City.

DEAR SIR:

Answering your inquiry of the 4th inst., in regard to the tunnel proposed by you for the delivery of the Catskill water from Hill View reservoir to the Boroughs of Manhattan and The Bronx, I beg to state that I am familiar with the general layout of the tunnel and uptakes proposed at various points within the Boroughs above mentioned, which I have discussed with you and your representative, and find that the tunnel as proposed is adequate for the purpose intended. Furthermore, the loss of pressure will be considerably diminished and the efficiency of the system correspondingly increased, both for domestic purpose and fire protection. Lastly, the cost of maintenance will be practically eliminated and no obstruction to traffic or disturbance of subsurface structures occasioned during the construction. Therefore, if, as I assume to be the case, sufficient borings have been taken and examinations made to show that the rock formation permits the construction of this tunnel within reasonable time and cost, I am of the opinion that it is a much cheaper and better method of delivering the Catskill water into our distribution system than the plan formerly proposed of effecting this delivery through large steel pipes laid under our streets and avenues.

Yours very truly,

I. M. DE VARONA,
Chief Engineer.

CITY OF NEW YORK
DEPARTMENT OF
WATER SUPPLY, GAS AND ELECTRICITY
BROOKLYN BOROUGH
BUREAU OF WATER

JOHN H. O'BRIEN
COMMISSIONER
WILLIAM C. COZIER
DEPUTY COMMISSIONER
WALTER E. SPEAR
CHIEF ENGINEER

Brooklyn, December 8, 1909.

J. WALDO SMITH, ESQ.,
Chief Engineer, Board of Water Supply,
299 Broadway, New York City.

DEAR SIR:

In compliance with your request of December 4, I present herewith my views regarding the plan proposed by the Board of Water Supply for the delivery of the Catskill supply to the Borough of Brooklyn.

In the first place, I cannot too strongly emphasize the necessity for a connection to Brooklyn by which to convey from the north a portion of the Catskill supply. With good fortune, Brooklyn's present sources of supply may suffice for several years to come, but early relief must be secured from new sources if a serious shortage of water is to be avoided.

The plan now proposed, as I understand it, provides for a conduit which has sufficient capacity to deliver 200 to 300 million gallons per day to Brooklyn at a head of 250 to 260 feet above sea level. The location of the proposed conduit in the center of the downtown manufacturing and commercial district of Brooklyn will deliver the soft Catskill water, where it should naturally have its greatest use for industrial purposes, and the design of the conduit will insure an uninterrupted service. It will be possible, at a small expense, to connect the proposed conduit to the trunk mains of either the Ridgewood or Mt. Prospect reservoir services, and there will be ample head to serve even the higher of these services. The plan will permit of a large extension of the limits of the Mt. Prospect service and thus provide an increase in the pressures

over large areas now inadequately served by the Ridgewood or low service.

The large capacity of the conduit leading to Brooklyn from the proposed Hill View reservoir will permit the delivery of sufficient water, when required, to meet the entire consumption of this borough for many years to come. This, in my opinion, is the most important feature of the plan now proposed, as it provides against any possible interruption of Brooklyn's supply through accident to the Ridgewood transportation works. As I understand the original plan, a pipe line of only 100 million gallons daily capacity was contemplated, and this being laid in the City streets, the supply to Brooklyn would have been liable to interruption. The daily delivery of 100 million gallons of water would not have met the requirements of Brooklyn without the construction of expensive storage reservoirs in this borough, which are not required by the present plan.

I beg further to state that the design of the proposed conduit contains nothing that has not been worked out elsewhere and I believe that the conduit as proposed will fully meet the requirements of service for which it is intended.

Respectfully,

WALTER E. SPEAR,
Chief Engineer

BOARD OF ESTIMATE AND APPORTIONMENT
OFFICE OF THE CHIEF ENGINEER

New York, December 8, 1909.

HON. GEORGE B. MCCLELLAN, MAYOR,
Chairman of the Board of Estimate and Apportionment.
SIR:

Under date of November 15, 1909, the Board of Water Supply submitted to the Board of Estimate and Apportionment a plan adopted by it on that date which is in part a modification of the general plan approved by the Board of Estimate and Apportionment on October 27, 1905 and which includes additions to that plan by providing for the Boroughs of Manhattan, The Bronx and Queens. A public hearing was given on this new plan on December 3, at the close of which the matter was referred to a committee consisting of an Engineer to be designated by the Board of Water Supply, the Chief Engineer of the Board of Estimate and Apportionment, the Chief Engineer of the Department of Finance, and Mr. Lindon Bates, Jr., with instructions to report back to the Board on Friday, December 10.

At the hearing of December 3 a number of objections were made to the present approval of the plan, these objections being based almost entirely upon the fact that the details of the plan were not known by the public and had not even been presented to the Board of Estimate and Apportionment, that the communication from the Board of Water Supply did not contain any estimates of cost, and that in fact there was no information before the Board of Estimate and Apportionment or available to the public which would justify the immediate approval of the plans.

Your Committee has devoted all the time at its disposal to a study of the plans and the investigations of the Board of Water Supply upon which they were based.

We beg to state that there is nothing unusual in the fact that the communication to the Board of Estimate and Apportionment did not contain or was not accompanied by an outline of the investigations which have been conducted or the estimates which have been made, and that the communication contained simply a recommendation for adoption predicated

upon certain results which would be secured by the proposed modification. To the members of the Committee who are conversant with the customary procedure in cases of this kind this was not surprising, as details rarely accompany communications to the Board, but are investigated by the technical staff of the Board or of the Finance Department, whose investigations and conclusions are submitted to the Board in the form of reports.

The modification in the present plan and the addition to the original plan are, briefly, as follows:

The general plan approved in 1905 provided for carrying the entire Catskill supply to the Hill View reservoir, just outside the City limits. It further provided for pipe lines from this reservoir through the Borough of The Bronx, with a tunnel under the East River, and through the Borough of Queens to a reservoir in the Borough of Brooklyn, with a further line across the Borough of Brooklyn and under the Narrows to a reservoir in the Borough of Richmond. No provision was made for supplying the Boroughs of Manhattan and The Bronx and Queens. The report accompanying these first plans distinctly stated that "The main distributing lines from Hill View reservoir to the Boroughs of Manhattan, Queens and The Bronx are matters for later consideration," and the estimates of cost accompanying the report do not include such lines. The amended plan provides for the elimination of the pipe lines from Hill View reservoir to the new Forest Park Reservoir, in the Borough of Brooklyn, and a new reservoir in the Borough of Richmond, which pipe lines we should note contemplate a service with no greater head than that now furnished in the Borough of Brooklyn. The plan substitutes for these lines a pressure tunnel through a portion of the Borough of The Bronx and under a greater part of the Borough of Manhattan and under the East River to a point in the vicinity of Flatbush avenue and Lafayette avenue, in the Borough of Brooklyn, from which point the new supply would be led to the Boroughs of Queens and Richmond. From shafts distant about four thousand feet from each other connections would be established with the present distribution systems of The Bronx and of Manhattan, and also a portion of the Borough of Brooklyn, while from the end of the tun-

nel section would radiate lines serving all of the last-named borough, the most of which are already in existence.

The Committee believes that the five considerations which are controlling in a study of these plans are as follows:

First—Time. Could the proposed pressure tunnel with the pipe line extensions be constructed as quickly as the pipe lines proposed in the first plan, or could it be constructed within the time at which Catskill water will be available?

Second—Cost. Will the expense of the proposed plan be greater or less than that of the original plan when there shall have been added to it provisions for the Boroughs of Manhattan, The Bronx and Queens?

Third—Practicability. Are there any engineering or construction problems involved in this plan, the solution of which is doubtful?

Fourth—Effect upon the present distribution system. Would the admission into present mains and pipes of water under a head of three hundred feet cause serious damage?

Fifth—Is the pressure tunnel with its pipe line extensions so located as to meet the probable demands of the near future?

The Board of Water Supply has placed at our disposal full information concerning the progress of work under the Rondout, Wallkill and Moodna siphons, all of which are tunnels fully as deep as the deepest of those in the proposed plan, and from the progress which has been made in both shafts and headings, the prediction that the longest section between shafts could be completed in about a year, while with an allowance of two and a half years for the assembling of plants, the sinking of shafts, the concreting of the tunnels, and the completion of connections, appears to justify the prediction that this tunnel will be available at least as soon as the Catskill water can be delivered to the City, which is estimated to be not less than four years.

The question of cost has been considered very carefully in an investigation made by Mr. William W. Brush, Department Engineer of the Board of Water Supply, the studies having been carried on for a year and a half and with careful and thorough discussion brought down to October 1, 1909, are included in a report made by him to the Chief Engineer of the

Board of Water Supply. We have carefully studied this report, as in our judgment the result of the investigations outlined will be controlling, not only as to cost, but in a great measure as to the other considerations already outlined.

Without going into details it appears that the cost per million gallons per day furnished through a pressure tunnel will be less than half the cost furnished through 66-inch steel pipes, and considerably less than one-third as much as though furnished through 48-inch cast-iron pipes. Careful detailed estimates further indicate that the actual cost of providing for 250 million gallons per day, which is the present development of the Esopus watershed now under way, through a pipe line system providing water for all five boroughs, and economically designed to take advantage of the mains in the present distribution system, will be almost precisely that of providing for 500 million gallons per day, or the entire Catskill development through the pressure tunnel with pipe line extensions as proposed in the amended plan, both estimates being $25,000,000, to which should be credited, however, the estimate for the pipe lines shown upon the original plan, which was $10,224,000, which shows an apparent additional cost of $15,000,000 to supply the Boroughs of Manhattan, The Bronx and Queens. It should be remembered, however, that the tunnel now proposed provides for a supply of 500 million gallons per day, instead of 250 million gallons per day, and at a head estimated to be 100 feet greater in Brooklyn than was provided for in the previous plan. If to this original plan for Brooklyn and Richmond is added a pipe line system for the boroughs not provided for (for a total quantity of 250 million gallons per day), it will increase the expense $15,000,000, or the same amount as for a tunnel plan of 500 million gallons per day capacity. If 500 million gallons per day were provided for by pipe lines for all boroughs, the estimated cost would be $47,000,000. If this amount is credited with the interest on deferred payment, and assuming that these lines will be added from time to time as needed, the net expense to the City will be $36,000,000, which is $11,000,000 greater than the estimated cost of the present plan.

As to the practicability, we find that the Engineers of the Board of Water Supply have consulted many engineers of

experience, including mining engineers, and that their unanimous opinion is that the driving of deep tunnels of the kind proposed involves no serious problems, and that in view of the preliminary investigations which have already been made there is no reason to doubt that the plan is entirely practicable. There is one point along the line where the borings have not yet been completed at sufficiently frequent intervals and at the requisite depth to determine the precise elevation at which the tunnel must be placed to insure satisfactory rock, but as additional depth involves no engineering difficulties, it seems safe to assume that this problem will be readily solved.

There appears to have been some doubt as to the effect upon the present distribution system of admitting to it a supply of water with this greatly increased head. We find, however, that this has been carefully considered, and that by the use of pressure control valves the amount of added pressure in the existing mains can be absolutely controlled and adapted to any pressure which the street mains or the house plumbing may be able to stand.

The final consideration concerns the location of the proposed tunnel and its pipe line extensions and their adaptability to meet the demands of the immediate future. It appears from the report of Mr. Brush and in statements made to the Committee that this matter has received very careful consideration, and that the tunnel and the pipe line extensions have been so located as to cross the present arteries of distribution in the Boroughs of Manhattan and Brooklyn, and that the present supply could be reinforced or increased with a minimum of expense as increased consumption may demand in any locality.

At the hearing before the Board of Estimate and Apportionment on Friday last the great desirability of providing at the earliest possible date for relief for the Borough of Brooklyn or for a physical connection which would permit a reinforcement of the supply in either Brooklyn or Manhattan in case of an emergency from the other boroughs was emphasized, and we believe that the tunnel under the East River will establish a connection of this kind which is much needed, and will do so in a shorter time than is practicable by any other method.

From the investigations made by your Committee we have reached the conclusion that the amended plan adopted and recommended by the Board of Water Supply has not been decided upon without thorough investigation and careful study, and it is our opinion that an unusually thorough investigation has been made and that the plan has been the subject of exceptionally critical and searching analysis in all its details before its presentation to the Board, and we would recommend that it be approved as submitted.

Respectfully,

NELSON P. LEWIS,
Chief Engineer, Board of Estimate and Apportionment.
CHANDLER WITHINGTON,
Chief Engineer, Department of Finance.
J. WALDO SMITH,
Chief Engineer, Board of Water Supply.

BOARD OF ESTIMATE AND APPORTIONMENT
OFFICE OF THE CHIEF ENGINEER

December 9, 1909.

HON. GEORGE B. MCCLELLAN, MAYOR,
Chairman of the Board of Estimate and Apportionment.
SIR:

The fourth member of the Committee, Mr. Lindon Bates, Jr., has met with the Committee at all of its sessions, and has joined in the inquiry, but has declined to concur in the report or to say to what portions he assents or to what he objects. He has filed a separate communication to his Honor the Mayor, which is herewith transmitted, together with the report of the majority of the Committee.

Respectfully,

NELSON P. LEWIS,
Chief Engineer, Chairman of the Committee.

December 10, 1909.

To the Mayor, Chairman, Board of Estimate and Apportionment, City of New York:

Regarding the application of the Board of Water Supply to the Board of Estimate for permission to alter the line of the Catskill distribution aqueduct from the present authorized location through Queens and Brooklyn to a location in Manhattan and the type of construction from a pipe system to a tunnel in general 200 feet and in places 600 feet deep it is to be noted:

1. That the cost of the tunnel system projected by the Board of Water Supply, of which all mention was omitted in their application of November 15, 1909, is estimated at $25,000,000.

2. That the plan presented by the Board of Water Supply in 1905, estimated at $10,224,000, which was passed with this resolution:

> Resolved, That the Board of Estimate and Apportionment does hereby approve and adopt said report, and the map, plan and profile accompanying the same, bearing the date of October 9, 1905; does hereby declare the same to be the final map, plan or plans approved and adopted by the Board of Estimate and Apportionment,

was not "final," but failed to provide for bringing water to Manhattan, The Bronx and Queens.

3. That this new tunnel plan will add $15,000,000 to the $161,857,000 estimated in 1905 for the Catskill system, unless economies in costs are made to this amount, which is unlikely so long as the condemnation "expenses" continue to be over $40 for every $100 worth of land taken, and the salary and overhead charges continue excessive.

4. That there are only a "hundred or more borings" on the profile sheet of the line, between Yonkers and Brooklyn, with occasional outcrop records. These borings are not sufficient for the purpose of obtaining reliable information as to the condition of the rock underlying the line of proposed tunnel. There is a section of nearly half a mile in the neighborhood of Clinton street, where only one boring, if any, has reached solid rock and where the contractors gave up work because of the unexpected depth.

5. The possibility of combining an east side, Bronx-to-Brooklyn passenger subway, with water conduits deserves consideration. At the time the present subway was built, its designer, William Barclay Parsons, most earnestly urged the construction of pipe galleries to carry the City water, gas and electrical conduits, upon the plea that once a tunnel had been cut the additional excavation necessary to include these pipes was comparatively inexpensive. The possibility of co-ordinating these great City enterprises rather than having each Department tear up streets, dig tunnels and lay pipes irrespective of what the others are doing, is worthy of careful investigation.

6. If a volume of leakage commensurate with that economized in other cities is made available there is a possibility that only 250 million gallons additional need be provided for upwards of twenty years. For every year that the expenditure of $49,000,000 for the second 250 million gallons of Catskill water and of $47,000,000 for Suffolk County extensions, can be postponed, there will be a saving in interest, amortization and maintenance of nearly $5,000,000 annually.

Since the recommendation of the Board of Water Supply, on which the Board of Estimate is requested to act, embodies no cost estimate and no exact statement of the work to be done; since the utilization of subway pipe galleries may be desirable and a less costly aqueduct practicable; since the City has nothing to gain by the immediate authorization of plans for which further modifications may be desirable, it is recommended that, in accordance with Section 3 of Chapter 724 of the Laws of 1905, the Board of Estimate "cause such surveys to be made and such further information to be obtained as it shall deem expedient to enable it to act intelligently in the premises."

Very respectfully,

LINDON BATES, JR.

BOARD OF ESTIMATE AND APPORTIONMENT
CITY OF NEW YORK

Whereas, The Board of Water Supply of The City of New York, pursuant to Chapter 724 of the Laws of 1905, as amended, has made such surveys, maps, plans, specifications, estimates and investigations as it deemed proper in order to ascertain the facts as to what sources for an additional supply of pure and wholesome water for The City of New York exist and are most available, desirable and best for the said supply, and

Whereas, The Board of Water Supply has reported to the Board of Estimate and Apportionment under date of November 15, 1909, recommending the approval of a map, plan and profile dated November 15, 1909, and entitled: "Board of Water Supply of The City of New York. Catskill Aqueduct. Map and profile showing manner of delivering the water to the several boroughs," and

Whereas, The Board of Estimate and Apportionment upon the receipt of said report and the said map, plan and profile, and on November 19, 1909, adopted a resolution that December 3, 1909, at 10.30 o'clock in the forenoon, at Room 16 in the City Hall, in The City of New York, be fixed as the time and place for a public hearing upon the said report, map, plan and profile, and that notice be given of such public hearing by publication in the City Record and in the newspapers designated by the Board of City Record as official City papers, and that the Secretary of the Board of Estimate and Apportionment give such notices as are provided for in said statute, and

Whereas, The Board of Estimate and Apportionment, in order to afford to all persons interested a reasonable opportunity to be heard respecting the said report, map, plan and profile, has given reasonable public notice of such hearing, and, in addition, has given notice of such hearing by mailing to the President of the Board of Aldermen of The City of New York and to the City Clerk of The City of New York, in behalf of the Counties of New York, Kings, Queens and Richmond, in which real estate to be acquired is situated, a notice of such hearing at least eight days before December 3, 1909, there being no Boards of Supervisors designated as such in any of said counties, and

Whereas, Notice of such hearing was mailed to the Chairman and the Clerk of the Board of Supervisors of Westchester County, at least eight days before December 3, 1909, and

Whereas, The said notice of said hearing was published in all of the papers specified and referred to above, being the City Record and The Sun, The New York Times, The Globe, The Evening Mail, Democracy, Tammany Times and Staats-Zeitung, the newspapers designated by the Board of City Record as official City papers, all of which is evidenced by the affidavits, certificates and documents filed in the office of the Secretary of the Board of Estimate and Apportionment, and

Whereas, On December 3, 1909, at 10.30 o'clock in the forenoon, in Room 16, in the City Hall, in The City of New York, the Board of Estimate and Apportionment met pursuant to said notice and a public hearing was given to all persons interested, and a reasonable opportunity to be heard respecting the said report, map, plan and profile was afforded to such persons, at which hearing said report, map, plan and profile were considered and due deliberation was had, now, therefore, be it

Resolved, That the Board of Estimate and Apportionment hereby approves and adopts the said report and map, plan and profile, both dated November 15, 1909, and hereby directs that the said map, plan and profile be executed, signed, certified and filed as directed in Section 3 of Chapter 724 of the Laws of 1905, as amended, and hereby declares the same to be the final map, plan or plans and profile approved and adopted by the Board of Estimate and Apportionment as provided for in said section; and be it further

Resolved, That an application be made by petition in writing to the State Water Supply Commission as speedily as possible for the approval of said report, map, plan and profile, pursuant to Chapter 56 of the Laws of 1909, being Chapter 54 of the Consolidated Laws known as the "State Boards and Commissions Law," and that the Corporation Counsel is hereby requested to prepare such papers and to take such steps with that end in view as may be proper.

Which was adopted by the following vote:

Affirmative—The Mayor, the Comptroller, the President of the Board of Aldermen, the Presidents of the Boroughs of The Bronx, Queens and Richmond and the Acting President of the Borough of Manhattan—14.

Negative—The President of the Borough of Brooklyn—2.

BOARD OF WATER SUPPLY
CITY OF NEW YORK
299 BROADWAY

COMMISSIONERS
J. A. BENSEL
CHARLES N. CHADWICK
CHARLES A. SHAW
THOMAS HASSETT, SECRETARY

New York, December 15, 1909.

STATE WATER SUPPLY COMMISSION,
Albany, N. Y.

GENTLEMEN:

We transmit to you herewith petition of The City of New York for the approval of the report, map, plan and profile, dated November 15, 1909, approved by the Board of Estimate and Apportionment of this City December 10, 1909, said map, plan and profile being entitled "Board of Water Supply of The City of New York. Catskill Aqueduct. Map and profile showing manner of delivering the water to the several Boroughs."

We also transmit to you herewith one of the originals of said map, plan and profile, duly signed by the members of this Board and by our engineers and by the representatives of the Board of Estimate and Apportionment.

We also send you herewith copy of report of Department Engineer William W. Brush to Chief Engineer J. Waldo Smith, copy of report of J. Waldo Smith to this Board, dated November 1, 1909, concurred in by Consulting Engineers Freeman, Burr and Noble, copy of report of a Committee appointed by the Board of Estimate and Apportionment, dated December 8, 1909, said Committee consisting of the Chief Engineer of this Board, the Chief Engineer of the Board of Estimate and Apportionment, the Chief Engineer of the Department of Finance of The City of New York.

We also beg leave to refer to you and to present as part of the City's application, all of the reports, testimony and data presented to your Commission in 1905 and 1906, at the time of the application of The City of New York for the approval

of the original map, plan and profile, dated October 9, 1905, which map, plan and profile, with certain immaterial exceptions, was approved by your Board May 14, 1906.

Respectfully,

THOS. HASSETT,

Secretary.

BEFORE THE STATE WATER SUPPLY COMMISSION

IN THE MATTER of The application of The City of New York to the State Water Supply Commission for the approval of the report of the Board of Water Supply of The City of New York to the Board of Estimate and Apportionment of The City of New York, dated November 15, 1909, recommending modification of the map, plan and profile dated October 9, 1905, approved by said Commission May 14, 1906, which modification is dated November 15, 1909, and is entitled " Board of Water Supply of The City of New York. Map and profile showing manner of delivering the water to the several Boroughs."	*Petition*

To the State Water Supply Commission:

The City of New York hereby respectfully makes application by petition in writing to the State Water Supply Commission, pursuant to the provisions of Chapter 724 of the Laws of 1905 and the acts amendatory thereof and supplemental thereto, and of Chapter 56 of the Laws of 1909, being Chapter 54 of the Consolidated Laws, and shows as follows:

1. The City of New York is a municipal corporation organized and existing in the State of New York by virtue of its ancient charters and the Laws of the Colony of New York and the Laws of the State of New York.

2. Pursuant to Chapter 724 of the Laws of 1905, and on or about June 9, 1905, the Mayor of The City of New York appointed J. Edward Simmons, Charles N. Chadwick and Charles A. Shaw to be a Board or Commission to be called Board of Water Supply of The City of New York. The said Commissioners duly qualified and entered upon the performance of their duties on or about the said date and have since continued to hold their said offices and to perform the duties thereof, except that on January 28, 1908, the said J. Edward

Simmons resigned his said office and on January 30, 1908, John A. Bensel was appointed by said Mayor to act as such Commissioner, and on January 31, 1908, said John A. Bensel duly qualified and entered upon the discharge of his duties and has ever since continued to hold said office and perform the duties thereof.

3. The Board of Water Supply proceeded pursuant to said statutes and made such surveys, maps, plans, specifications, estimates and investigations as they deemed proper in order to ascertain the facts as to what sources for an additional supply of pure and wholesome water for The City of New York exist and are most available, desirable and best for the said City, and under date of November 15, 1909, reported to the Board of Estimate and Apportionment of The City of New York recommending the delivery of the water to the several boroughs of said City. A copy of said report is hereto annexed marked "A," and is made a part of this petition. Accompanying said report was a map, plan and profile dated November 15, 1909, entitled " Board of Water Supply of The City of New York. Map and profile showing manner of delivering the water to the several boroughs." Said map, plan and profile was duly signed by said Commissioners and their engineers. Said map, plan and profile and the other papers and documents accompanying this application form an exhibit of maps of lands to be acquired and profiles thereof showing the sites and areas of the proposed reservoirs and other works, the profiles of the aqueduct lines and the flow lines of the water when impounded, also plans and surveys and abstracts of official reports relating to the same, showing the need of The City of New York for the delivery of the Catskill water to the several boroughs of said City and the reasons therefor. This petition is accompanied by proof as to the character and purity of the water supply proposed to be acquired and delivered.

4. The Board of Estimate and Apportionment, upon the receipt of said report, map, plan and profile and prior to the adoption thereof, did afford to all persons interested a reasonable opportunity to be heard respecting the same and did give reasonable public notice of such hearing whereat testimony might be produced by the parties appearing in such manner as

the Board of Estimate and Apportionment might determine. On November 19, 1909, the Board of Estimate and Apportionment adopted a resolution in the following terms:

"Whereas, The Board of Water Supply of The City of New York, pursuant to Chapter 724 of the Laws of 1905, as amended, has submitted to the Board of Estimate and Apportionment a report and plan which bears the date of November 15, 1909, and is entitled 'Map and profile showing manner of delivering the water to the several boroughs,' said map being now on file in the office of the Board of Water Supply of The City of New York, No. 299 Broadway, New York City; now therefore be it

"Resolved, That the 3rd day of December, 1909, at 10.30 o'clock in the forenoon, at Room 16, in the City Hall, in The City of New York, be fixed as the time and place for a public hearing upon the said report and plans, and that notice be given of such public hearing by publication in the City Record, and in the newspapers designated by the Board of City Record as official City papers; and be it further

"Resolved, That the Secretary of this Board be directed to give such notices as are provided for in said statute."

5. Pursuant to the terms of said resolution a notice of said public hearing on December 3, 1909, was duly published in the City Record, and in the Sun, Times, Globe, Evening Mail, Democracy, Tammany Times and Staats-Zeitung, being the newspapers designated by the Board of City Record as official City papers. Notice of said public hearing on December 3, 1909, was also duly given pursuant to the provisions of Section 3 of Chapter 724 of the Laws of 1905, as amended, by mailing to the President of the Board of Aldermen of The City of New York, and to the City Clerk of The City of New York, in behalf of the counties of New York, Kings, Queens and Richmond, where real estate to be acquired is situated, a notice of such hearing at least eight days before the time named in said notice, there being no Board of Supervisors in any of said four counties designated as such; and by mailing such notice to the Chairman and Clerk of the Board of Supervisors of Westchester County at least eight days before De-

cember 3, 1909. All of said facts will more fully appear from the records on file in the office of the Secretary of the said Board of Estimate and Apportionment, all of which the petitioner herein begs leave to refer to and to produce.

6. Said hearing before the Board of Estimate and Apportionment was duly had on December 3, 1909, at 10.30 o'clock in the forenoon, at Room 16, in the City Hall, Borough of Manhattan, City of New York, being the time and place duly set therefor, and was duly adjourned to December 10, 1909. At said hearing the Board of Estimate and Apportionment heard all who appeared in opposition to the approval of the said report, map, plan and profile, and all who appeared in favor thereof. On December 10, 1909, after due deliberation said Board of Estimate and Apportionment duly adopted a resolution approving and adopting the said report, map, plan and profile. Said resolution is as follows:

> "Whereas, The Board of Water Supply of The City of New York, pursuant to Chapter 724 of the Laws of 1905, as amended, has made such surveys, maps, plans, specifications, estimates and investigations as it deemed proper, in order to ascertain the facts as to what sources for an additional supply of pure and wholesome water for The City of New York exist and are most available, desirable and best for the said supply, and
>
> "Whereas, The Board of Water Supply has reported to the Board of Estimate and Apportionment under date of November 15, 1909, recommending the approval of a map, plan and profile dated November 15, 1909, and entitled: 'Board of Water Supply of The City of New York. Catskill Aqueduct. Map and profile showing manner of delivering the water to the several boroughs,' and
>
> "Whereas, The Board of Estimate and Apportionment upon the receipt of said report and the said map, plan and profile, and on November 19, 1909, adopted a resolution that December 3, 1909, at 10.30 o'clock in the forenoon, at Room 16 in the City Hall, in The City of New York, be fixed as the time and place for a public hearing upon the said report, map, plan and profile, and that notice be given of such public hearing by publication in the City Record and in the newspapers designated by

the Board of City Record as official City papers, and that the Secretary of the Board of Estimate and Apportionment give such notices as are provided for in said statute, and

" Whereas, The Board of Estimate and Apportionment, in order to afford to all persons interested a reasonable opportunity to be heard respecting the said report, map, plan and profile, has given reasonable public notice of such hearing, and, in addition, has given notice of such hearing by mailing to the President of the Board of Aldermen of The City of New York and to the City Clerk of The City of New York, in behalf of the Counties of New York, Kings, Queens and Richmond, in which real estate to be acquired is situated, a notice of such hearing at least eight days before December 3, 1909, there being no Boards of Supervisors designated as such in any of said counties, and

" Whereas, Notice of such hearing was mailed to the Chairman and the Clerk of the Board of Supervisors of Westchester County, at least eight days before December 3rd, 1909, and

" Whereas, The said notice of said hearing was published in all of the papers specified and referred to above, being the City Record, and The Sun, The New York Times, The Globe, The Evening Mail, Democracy, Tammany Times and Staats-Zeitung, the newspapers designated by the Board of City Record as official City papers, all of which is evidenced by the affidavits, certificates and documents filed in the office of the Secretary of the Board of Estimate and Apportionment, and

" Whereas, On December 3, 1909, at 10.30 o'clock in the forenoon, in Room 16, in the City Hall, in The City of New York, the Board of Estimate and Apportionment met pursuant to said notice and a public hearing was given to all persons interested, and a reasonable opportunity to be heard respecting the said report, map, plan and profile was afforded to such persons, at which hearing said report, map, plan and profile were considered and due deliberation was had,

" Now, Therefore, be it

" Resolved, That the Board of Estimate and Apportionment hereby approves and adopts the said report and map, plan and profile, both dated November 15, 1909, and hereby directs that the said map, plan and profile be executed, signed, certified and filed as directed in Section 3 of Chapter 724 of the Laws of 1905, as amended, and hereby declares the same to be the final map, plan or plans and profile approved and adopted by the Board of Estimate and Apportionment as provided for in said section; and be it further

" Resolved, That an application be made by petition in writing to the State Water Supply Commission as speedily as possible for the approval of said report, map, plan and profile, pursuant to Chapter 56 of the Laws of 1909, being Chapter 54 of the Consolidated Laws known as the ' State Boards and Commissions Law ' and that the Corporation Counsel is hereby requested to prepare such papers and to take such steps with that end in view as may be proper."

7. After the approval and adoption of said report, map, plan and profile, the said map was duly executed in quadruplicate. One thereof accompanies this petition and is intended to be filed herewith and made a part hereof. A second remains on file with the Clerk of the Board of Estimate and Apportionment. A third is placed on file in the office of the Board of Water Supply. A fourth is filed in the office of the Commissioner of Water Supply, Gas and Electricity of the City of New York. A certified copy of said map is filed in the office of the County Clerk or Register of each of the counties in which the real estate affected thereby is situated. A copy of the said report of the Board of Water Supply of The City of New York to the Board of Estimate and Apportionment, dated November 15, 1909, is also herewith presented, together with an abstract of official reports relating to the manner of delivering the water to the several boroughs of The City of New York, and showing the need for the delivery of such water to The City of New York and the reasons therefor. In addition, The City of New York herewith presents a plan or scheme to determine and provide for the pay-

ment of the proper compensation for any and all damages to persons and property, whether direct or indirect, which will result from the acquiring of said lands and the execution of said plans. All of said matters will be more fully shown in the proceedings, papers and documents which will be produced at the hearing before the State Water Supply Commission.

8. The proposed delivery of such water to the said several boroughs and the execution of the plans herewith presented are justified by public necessity and are just and equitable to the other municipalities and civil divisions of the State affected thereby and to the inhabitants thereof, particular consideration being given to their present and future necessities for sources of water supply.

9. The plan or scheme to determine and provide for the payment of proper compensation for any and all damages to persons or property, whether direct or indirect, which will result from the acquiring of the said lands and the execution of the said plans, is to purchase the said lands and to secure conveyances and releases thereof if the amount can be agreed upon, and if not to acquire the same by condemnation proceedings, as provided in Chapter 724 of the Laws of 1905 and the acts amendatory thereof and supplemental thereto. The City of New York is of abundant financial responsibility to pay any and all of the aforesaid damages. It is proposed to pay all such claims from the proceeds of Corporate Stock to be issued from time to time by the Comptroller when thereto authorized by the Board of Estimate and Apportionment.

Wherefore The City of New York hereby makes application by petition in writing to the State Water Supply Commission for the approval of the said report, map, plan and profile, and has caused this petition to be subscribed by its Mayor and by its City Clerk and its seal to be affixed hereto this 15th day of December, 1909.

GEORGE B. McCLELLAN,
[L. S.] *Mayor.*

P. J. SCULLY,
City Clerk.

FRANCIS K. PENDLETON,
Corporation Counsel.

STATE OF NEW YORK
COUNTY OF NEW YORK } *ss.:*
CITY OF NEW YORK

On the 15th day of December, in the year 1909, before me personally came P. J. Scully, with whom I am personally acquainted, and who is known to me to be the City Clerk of The City of New York, who being by me duly sworn did depose and say:

I reside in the Borough of Manhattan, City of New York. I am City Clerk of The City of New York, the corporation described in and which executed the foregoing petition. I know the seal of said corporation. The seal affixed to said petition is such corporate seal. It was thereto affixed by due authority of said corporation, and I signed my name thereto as City Clerk by like authority. I know George B. McClellan and know him to be the person described in and who as Mayor of The City of New York executed said petition. I saw him subscribe and execute the same, and he acknowledged to me, the said P. J. Scully, that he executed and delivered the same, and I thereupon subscribed my name thereto.

CHAS. A. GLASER,
Commissioner of Deeds,
New York City.

STATE OF NEW YORK,
STATE WATER SUPPLY COMMISSION.

In the Matter
of
the Application of The City of New York.

Public Notice.

Notice is hereby given that, pursuant to the provisions of Chapter 724 of the Laws of 1905 and the acts amendatory thereof and supplemental thereto, and to Article 2 of the State Boards and Commissions Law, being Chapter 56 of the Laws of 1909, the State Water Supply Commission will meet at the office of the Board of Water Supply, No. 299 Broadway, in the Borough of Manhattan, City of New York, on the 12th day of January, 1910, at 11 o'clock in the forenoon of that day for the purpose of hearing all persons, municipal corporations or other civil divisions of the State of New York that may be affected by the execution of the modification, or amendment, dated November 15, 1909, of the plans of The City of New York for securing a new and additional supply of water, plans for which modification or amendment have been filed with the New York State Water Supply Commission, at its office, Lyon Block, Albany, N. Y., where the same are open for public inspection; and for the purpose of determining whether said plans are justified by public necessity and whether the same are just and equitable to the other municipalities and civil divisions of the State of New York and to the inhabitants thereof affected thereby, and whether said plans make fair and equitable provisions for the determination and payment of any and all damages to persons and property, both direct and indirect, which will result from the execution thereof.

The execution of such plans, it is alleged, will affect lands situate in the Counties of New York, Kings, Queens and Richmond.

All persons, municipal corporations and other civil divisions of the State of New York who have objection to the execution of said plans, in order to be heard thereon, must file such

objections thereto in writing in the office of the State Water Supply Commission in the city of Albany, N. Y., on or before the 11th day of January, 1910. Every objection so filed must particularly specify the grounds thereof.

No person, municipal corporation or local authority can be heard in opposition thereto except on objections so filed.

Dated, Albany, N. Y., December 16, 1909.

HENRY H. PERSONS,
President.
ERNST J. LEDERLE,
MILO M. ACKER,
JOHN A. SLEICHER,
CHARLES DAVIS,
State Water Supply Commission.

BOARD OF ESTIMATE AND APPORTIONMENT
CITY OF NEW YORK
OFFICE OF THE SECRETARY
277 BROADWAY

New York, January 7, 1910.

MR. THOMAS HASSETT, SECRETARY,
Board of Water Supply,
299 Broadway,
New York City.

DEAR SIR:

I transmit herewith certified copy of a resolution adopted by the Board of Estimate and Apportionment at the meeting held this day, requesting the State Water Supply Commission to defer final action upon any projected extensions or modifications of New York's Water Supply System.

I am informed that the State Board will, on January 12, 1910, consider the plan of Water Supply Extension in the County of Suffolk, adopted by the Board of Estimate and Apportionment on June 26, 1908, and the plan of the Water Supply Pressure Tunnel under the Borough of Manhattan, adopted by the Board of Estimate and Apportionment on December 10, 1909.

Respectfully,

JOSEPH HAAG,
Secretary.

Whereas, The Board of Estimate and Apportionment on June 26, 1908, approved of a plan of water supply extension in the County of Suffolk, and under date of December 10, 1909, approved of a water supply pressure tunnel under the Borough of Manhattan, both of which matters are under the jurisdiction of the Board of Water Supply and are now under consideration by the State Water Supply Commission.

Resolved, That the Board of Estimate and Apportionment request the State Water Supply Commission to defer final action upon any projected extensions or modifications of New York's Water Supply System.

I hereby certify that the foregoing is a true copy of a resolution adopted by the Board of Estimate and Apportionment of The City of New York at a meeting of said Board held on January 7, 1910.

JOSEPH HAAG,
Secretary.

BOARD OF ESTIMATE AND APPORTIONMENT
CITY OF NEW YORK
OFFICE OF THE SECRETARY
277 BROADWAY

March 4, 1910.

THOMAS H. KEOGH, ESQ.,
Secretary, Board of Water Supply,
299 Broadway, New York City.

DEAR SIR:

I transmit herewith certified copy of resolution adopted by the Board of Estimate and Apportionment March 4, 1910, providing for the appointment of a Committee of three, with instructions to retain as expert advisers two engineers and a geologist, on the matter of the construction of a pressure tunnel under Manhattan Island from Hill View reservoir to the Borough of Brooklyn, and to report thereon to said Board at the earliest possible moment.

In accordance with the provisions of the resolution the Mayor appointed the President of the Board of Aldermen, the Comptroller and the President of the Borough of Manhattan as members of the Committee.

Respectfully,

JOSEPH HAAG,
Secretary.

BOARD OF ESTIMATE AND APPORTIONMENT
CITY OF NEW YORK

Whereas, the former Board of Estimate and Apportionment did on December 10, 1909, authorize a modification of the general plan of the Board of Water Supply contemplating the construction of a pressure tunnel under Manhattan Island from Hill View reservoir to the Borough of Brooklyn, and

Whereas, the present Board of Estimate and Apportionment did by resolution introduced on January 7, 1910, request the State Board of Water Supply to suspend action for approval of this modification until an opportunity had been had for examination into the merits of the plan; now, therefore, be it

Resolved, That a committee of three be appointed with instructions to retain as expert advisers two engineers and a geologist, and that the committee be instructed to examine into the engineering feasibility of the proposed pressure tunnel and to report thereon at the earliest possible moment to this Board.

I hereby certify that the foregoing is a true copy of a resolution adopted by the Board of Estimate and Apportionment at the meeting of said Board, held on the 4th day of March, 1910.

JOSEPH HAAG,
Secretary.

REPORT ON DISTRIBUTION OF CATSKILL WATER SUPPLY IN NEW YORK CITY

Hon. WM. A. PRENDERGAST, *Hon.* JOHN PURROY MITCHEL and *Hon.* GEORGE MCANENY, *Committee of the Board of Estimate and Apportionment of The City of New York.*

GENTLEMEN—The undersigned, acting by reason of your letters to them of March 25 and 28, 1910, respectfully report:

In answer to the first question asked us, namely: "Is the proposed Manhattan tunnel practicable, from an engineering and geological standpoint," we say as follows:

PRACTICABILITY—MANHATTAN PRESSURE TUNNEL

The proposed Manhattan tunnel is to be a "pressure tunnel," running from the proposed Hill View reservoir, located at the downstream end of the Catskill water supply conduit now under construction and about half completed, thence passing under the westerly part of the middle of Manhattan Island, and thence across to Brooklyn. Its route has been thus selected so as to cause the tunnel to pass through a territory promising, for geological reasons, to be the best that can be found between the end points described. In carrying capacity it is gradually to diminish from Hill View to Brooklyn.

A "pressure tunnel," which is thus designated on account of its being designed to convey water under pressure, must be placed, as usually constructed, at such a depth below the surface of the ground, that the weight per square foot of the overlying material is at least equal to the pressure per square foot upwards of the contained water.

Such a location, as regards depth below the surface, places no reliance on the strength, or resistance to rupture, of the surrounding ledge-rock, and is therefore conservatively safe.

In the present instance this method of construction places the tunnel about 200 feet below the street level, but for purposes of crossing in good rock, under the Harlem river, Manhattanville valley and the East river, this depth is increased to about 350 feet and to not less than about 600 feet respectively, kept elsewhere at not less than 150 feet beneath the "rock floor."

Borings, Making and Completed

To explore the nature of the ground, and when necessary to find lower down the rock floor referred to, bore holes have been put down, since December, 1908, all along the line described. This line passes under streets, parks and other property of the City, some eighteen miles, with the exception only of about a quarter of a mile of right of way to be acquired. One hundred and twenty-five such bore holes have been completed, and at least thirty more have been begun, or are planned, extending in many cases to the proposed tunnel grade. This will give indications of the nature of the ground to be met with in tunneling, much more complete and instructive than formed the basis of the location of other pressure tunnels that have been built in years past. It should be remembered in this connection that the art of making borings and of extracting core specimens of rock penetrated is constantly advancing, no less than other arts. No such knowledge beforehand of conditions to be encountered, as is now available, was at hand, for instance, for the builders of the Harlem River crossing of the new Croton Aqueduct pressure tunnel built twenty years ago. Nor for the construction of certain other such tunnels, built since that time.

Available Data

We have carefully studied the geological data thus and otherwise made available, including the experiences had in other tunneling operations in this vicinity, such as the construction of the Harlem River pressure tunnel, built in 1885-1891, just mentioned; the Pennsylvania Railroad tunnels, lately completed; the Webster Avenue sewer, running to the Harlem river; the Bronx Valley storm relief sewer, now under construction; the Rondout, Wallkill and Moodna pressure tunnels, forming a part of the new Catskill water supply, two of them built at a level of 200 feet below sea level, which we have personally examined, the Steinway tunnel and the East River gas tunnel; the Battery tunnel to Brooklyn, and certain shafts put down in Manhattan borough.

We have gone over the whole length of the line described, from the East river to Hill View, and have examined rock

cores or specimens brought up in the making of the bore holes named, which are preserved for future use in the letting of the construction contracts, at the 92nd Street gate-house. We have also studied, up to date, the weekly reports made concerning the bore holes now being put down.

Geological Conclusions

From a detailed examination of all the geological data accessible, we are of opinion that the construction of a pressure tunnel along the line laid down on the plans of the Board of Water Supply, and its subsequent maintenance, are entirely practicable. Keeping in mind the geology of the district to be traversed, which we regard as unusually well explored, it seems unlikely that such seams, soft spots, loose pockets, faults or zones of crushing or of deep decay should be met, even for short distances, as will render impracticable the proper construction of the tunnel at the depths proposed; and it does not appear at this writing probable even that such conditions will be met, as will require any material change from the present plans of the Board of Water Supply, with the possible exceptions noted below.

Concerning a short distance across the lower east side of Manhattan, from the corner of Spring street and the Bowery to the river front at Clinton street, the geological data are still incomplete. From the condition of the deep rock, as shown by gross and microscopic examination of rock cores from this field, we are convinced that this section also is a practicable route substantially as proposed; but final judgment must be deferred upon the depth and character of the tunnel, the cost and upon the time required for the construction of the shafts and tunnels in this section, pending the completion of the boring operations conducted by the Board of Water Supply. The same may be said concerning the line for a distance of about 1,000 feet on 106th street. Detailed geological data upon which these deductions are based are discussed in Appendices A, B and C.

Other Pressure Tunnels in the United States

Pressure tunnels, so far as we are informed, had their beginning in the United States right here in New York, the

Harlem River crossing of the new Croton aqueduct, 1885-1891, being the first pressure tunnel built, so far as we know; seven miles long, and containing a pressure of 103 feet of water (about 45 pounds per square inch).

The accomplished Chief Engineer of this work, the late Mr. A. Fteley, on page 87 of his report dated January 1, 1895, says this concerning the Harlem River crossing tunnel: "This feature, that is, the construction of the aqueduct for seven miles, under pressure, is a bold innovation."

However the point of priority may be decided, true it is that the Harlem River pressure tunnel has been in every way a complete success for the twenty years of its existence in service; and others have not hesitated to profit by its example.

Thus there is a pressure tunnel under the City of Washington, put into service in 1898, after it had lain defective, unfinished and idle for a period of nigh ten years, 4 miles long, and carrying a pressure of 123 feet of water (53 pounds per square inch). One thousand feet of it, where it passes under Rock creek, is lined with cast-iron rings. The Board of Engineers, who reported in 1896 recommending the completion of the tunnel, were divided in opinion whether the safe transit of these 1,000 feet under the Rock Creek valley should be made by going deeper and into sound rock for that length or by lining the tunnel, some 9 feet in diameter, with cast-iron rings. The lining method was adopted, and there is no doubt that the other method would have given equally good results.

The history of both pressure tunnels and of conduits not under pressure built by tunneling methods (and much such history has been written in the United States in the past twenty-five years) plainly teaches what are the essentials of good design, and also the necessity on the part of the supervising engineer to see to it that the conditions of the specifications be carried out during construction.

There can no longer be any doubt that good design as well as faithful performance of the specifications can now be secured.

Pressure tunnels carrying 60, 37 and 21 feet of water pressure are in service at Cincinnati, Kansas City and Philadelphia, built between 1900 and 1906; and many others, built so as to run full of water, but carrying no unbalanced pressure,

are in use in the United States. The Cincinnati tunnel is noted for having been constructed in the face of a greater than the usually found quantity of inflow of water, due to the seamy, soft yellow limestone of the Ohio valley through which this tunnel passes.

An instructive example of the practicabilities of such structures, even when at first of defective design, is given by the pressure tunnel, in effect the penstock or pipe carrying the power water, to the Kern River hydro-electric plant of the Southern California Edison Company, of Los Angeles, California. Parts of this tunnel act under a pressure of about 870 feet (about 380 pounds per square inch), about double the pressure put on a modern high pressure steam boiler.

This tunnel, as first completed in 1907, had no proper location or lining to resist either internal or external pressure. Nevertheless, by the skillful design and thorough work of the present Vice-President and General Manager, it has been restored to its intended usefulness, and has been in service since September 1, 1909.

The many acres of ledge rock, honeycombed with tunnels which were placed with their roof within some 20 feet of the bottom of the river and used in the removal of obstructions to navigation at Hell Gate, in the East river, form another well known illustration in this vicinity of practicable tunneling carried on in submerged rock, close to and directly under the river.

Opinion

An unusually complete collection of geological data and the results of borings already made thus make it highly probable that none but the ordinary difficulties of plain tunneling will be met with in the construction of the proposed Manhattan pressure tunnel; and the experience had in the construction of other pressure tunnels in this vicinity and elsewhere in the United States during the past twenty-five years change this probability into a certainty that the proposed pressure tunnel is practicable. Whatever bad ground may be revealed by the actual work of tunnel building, which the borings made and yet to be made have not revealed, can be passed through, over, under or around by methods that have been used in the like cases elsewhere and at no extraordinary cost.

We therefore answer in the affirmative your first question: "Is the proposed Manhattan tunnel practicable from an engineering and geological standpoint?"

Comparative Projects

Your second question is: "How does the estimated and probable cost of this tunnel compare with (a) the estimated and probable cost of a pipe line from Hill View reservoir through Queens to the Borough of Manhattan, and (b) a pressure tunnel from Hill View through Queens to Brooklyn?"

The question is intended, we assume, to call for comparisons of cost on the routes and of the kinds of water conduits described, when built of equal water and pressure carrying capacity, and serving an equal area of distribution, as otherwise a comparison could not be made.

The proposed Manhattan pressure tunnel, like the Catskill aqueduct, now building, is to carry at its upstream end a supply of 500 million gallons daily; and passing, in gradually diminishing sizes, to Brooklyn through the Boroughs of The Bronx and Manhattan, will supply the distribution systems of these three Boroughs at a pressure, where desired, of about 100 feet (43 pounds per square inch) greater than at present; and by pipe-line extensions it will also thus supply the Boroughs of Queens and Richmond; that is: at pressures, where desired, of about 275 feet in The Bronx; 280 feet in Manhattan; 245 feet in Queens; and 225 feet in Richmond; while any conduit built on the line direct from Hill View through Queens to Brooklyn will necessarily demand other and additional conduits also to supply Manhattan Island.

Increased Pressure When Desired

We cannot assume that no portion of the Catskill water-supply will at no time be needed in the Borough of Manhattan. We believe, on the contrary, that its delivery under the increased pressure, nearly 100 feet (43 pounds per square inch) of increased pressure, which the proposed Manhattan pressure tunnel would furnish, would be of very great value to the Borough of Manhattan to-day, and for all time, in giving eventually the chief city of the United States a pressure in its supply for fire and domestic purposes such as is customary in

other cities and in villages of the United States, and in relieving the city from a very great daily expense of pumping water those same 100 feet at high service City pumping-stations and also at thousands of privately owned pumping engine plants of all kinds located in dwellings and other buildings.

The Manhattan pressure tunnel is designed to deliver water at many uptake shafts, placed at intervals of about 4,000 feet throughout its length of nearly eighteen miles, at any locally desired pressure (up to its limit of action), by means of pressure regulators, so that no fear of an undue overloading of the strength of the street mains or of plumbing need be entertained. Water pressure in cities has money value and is sought for and quickly utilized whenever available. In the course of years all fixtures are, when necessary, rebuilt to suit the increased pressure, and meantime any district or single buildings within any district may be kept supplied at the former pressure, if so desired, by the use of the simple and inexpensive appliance known as a pressure regulator. It is thus made practicably expedient to introduce the more desirable and valuable street main pressure gradually and as it may be called for by the water consumers. As reducing insurance rates alone, such increased pressure is palpably of very great value.

Pumping to Be Dispensed With

The present high service pumping above mentioned amounts to about 75 million gallons daily in Manhattan, 25 million gallons in Brooklyn and 30 million gallons by the pumps of citizens, 130 million gallons daily in all, costing at the City pumping-stations about $400,000 annually; at the private pumping plants a sum difficult to estimate, but by careful inquiry and conservative estimate this has been found to amount to not less than the great sum of $1,400,000 annually, a total of $1,800,000 annually, when the estimates were made, which in a few years will certainly amount to at least $2,000,000 annually, representing a capital of some $50,000,000.

Brooklyn Pumping Wholly to Be Dispensed With for a Time

Nor do even these estimates represent all possible saving in expenses now incurred for pumping. As is well known

to the Department of Water Supply, Gas and Electricity, all the pumping-stations in the Borough of Brooklyn, both low service and high service, the two now costing for operation about $1,000,000 annually, without counting renewal fund and repairs, could be advantageously shut down for ten years if the Brooklyn distribution system could take its supply of water from the proposed Manhattan pressure tunnel.

Over $200,000 annually is also spent in Brooklyn in the purchase of water from private water companies, which may also be saved.

It is well known that a thorough repair, in most cases a rearrangement, of the Brooklyn pumping-station machinery would quickly pay for itself in a saving of undue cost of operation; but this has not been and is not now possible on account of the constant great overload and strain to which these works have been and are subjected. To give opportunity, therefore, for a rearrangement or for the rehabilitating of the pumping-stations of Brooklyn would be not the least of the valuable services which the proposed Manhattan pressure tunnel would give to the interests of the City.

Consumption of Catskill Water in Manhattan

Returning to the consideration of the idea not to allow any of the Catskill water-supply ever to be distributed in Manhattan island, we find that within about thirty years no less than 180 millon gallons daily of this supply will be needed in the Borough of Manhattan, even if the whole of the Croton water-supply be reserved in addition and for Manhattan exclusively, which shows that a conduit of some sort from Hill View to Manhattan must be constructed.

Cross-Connection, Manhattan-Brooklyn

Nor can we assume that there is no value in a cross-connection of great carrying capacity between Manhattan and Brooklyn. We believe, on the contrary, that a cross-connection between these two boroughs and their main distribution reservoirs, such as the Manhattan pressure tunnel would create, will for all time be of great value in the safe and prudent operation of the water-supply of the great City of New York,

and should be acquired as soon as this may expediently be done. To be most effective it should connect by properly dimensioned conduits the Central Park and Brooklyn reservoirs.

Parallel Lines of Water Mains

Even then the two plans referred to could not be compared merely on the basis of first cost. A pressure tunnel has practically no maintenance charges, while pipe-lines are subject to accidental breakage, if of cast iron, and to comparatively great renewal charges if of steel. Especially objectionable are parallel lines of such large pipes laid closely together, as they would have to be laid in city streets. Mr. A. Fteley, Chief Engineer of the New Croton aqueduct, felt so strongly on this subject that he recorded his objections to the eight 48-inch pipe-lines laid in Convent avenue (page 88 of his Report, dated January 1, 1895), even after these pipes had been long laid and in service. Should one such pipe of a parallel row of pipes break there is always danger of its undermining its neighbors, until all the pipes are broken.

There is also to be considered the advantages to the City in having work go on in tunnels, under cover, and without annoyance to street traffic of all kinds, rather than undertake to lay large water pipes in streets already excessively encumbered with underground pipes, conduits, sewers, subways and other subsurface structures, with more to come, and with an ever increasing street traffic to be served at all times.

First Cost Comparisons

But barring those accompanying advantages of the pressure tunnel plan whose money values cannot be readily computed, our comparisons must be made between the first cost of the proposed Manhattan pressure tunnel and the first cost (a) of a pipe-line from Hill View reservoir through Queens to the Borough of Brooklyn, supplemented by a pipe-line from Hill View to Manhattan, together with a cross-connection direct between Brooklyn and Manhattan, all of this of equal carrying capacity and distributing capacity to the Manhattan pressure tunnel first named; also (b) between the first cost of the proposed Manhattan pressure tunnel and the first cost of a

pressure tunnel substituted for the pipe-lines just described under letter (a), this last being a comparison of first cost between two pressure tunnels built on two different routes.

This Queens and Brooklyn pressure tunnel must, for purposes of enabling a comparison to be made, be supplemented (as was the pipe-line) by a good and sufficient pipe-line from Hill View to Manhattan, and by a proper direct cross-connection, Brooklyn to Manhattan.

Comparing now our estimated probable first cost and time necessary for completion of the Manhattan pressure tunnel, with the estimated probable first cost and time necessary for completion of an equivalent pipe-line (your question 2, under letter a) we find that the Manhattan pressure tunnel will cost about $26,000,000, and will require about four and one-quarter years to construct, while an equivalent pipe-line system will cost about $47,000,000 and will require about four and one-half years to construct; a saving of first cost of a pressure tunnel as compared with pipe-lines of $21,000,000. For details of which statement reference is had to Appendices D, E, F and G.

Route Comparison

Taking up our consideration of a comparison of the two pressure tunnels, Hill View via Manhattan to Brooklyn, and Hill View via Queens to Brooklyn (the subject outlined by Question 2, b), we are met with the fact that no borings exist on the Wards Island route. Consequently, over a year's time would be lost on that line in exploring the subsurface. The topography of this portion of the country shows a large and broad area over which the rock floor is depressed below sea-level; and it is known that the zone of disturbed rock occupying in general the valley of East river is broader here than further south. A tunnel on this route would be obliged to cross more rock contacts and traverse greater stretches of poor ground than by the route now proposed. These conditions argue strongly against the practicability of this route; but on account of a lack of detailed information as to the conditions to be encountered, a comparative estimate of the tunnel: Hill View via Queens to Brooklyn, scheduled under Question 2, b, can hardly be made.

We only know that with equally good ground to be met with, the Manhattan tunnel would cost less; being on a direct and central line that is capable of supplying all the five Boroughs; and not needing the supplements of a separate and special line to supply Manhattan, and of a separate and special cross-connection between Brooklyn and Manhattan.

Question 3

Our answer under Question 2, b, just stated, naturally applies also to Question 3:

"Which in your opinion is the better route for a pressure tunnel if constructed. (a) from Hill View reservoir, through Queens to Brooklyn, or (b) from Hill View reservoir, through Manhattan island to Brooklyn."

Conclusion

If we were tersely to sum up the considerations which are not included in a mere comparison of first costs, as presented by the three questions we have answered, and to emphasize the value of the advantages which the proposed Manhattan pressure tunnel will confer upon the City, such as increased pressure gained (a very valuable item in the way of saving fire insurance, and in saving pumping expenses, as already shown), no encumbrances of streets during construction, nor of their subsoil thereafter, and the like considerations, we should say that The City of New York must have the Manhattan pressure tunnel to distribute the Catskill water-supply, or its equivalent; and from the results of our studies, we find that the Manhattan pressure tunnel may be constructed at much less cost, with less annoyance and immediate danger during construction, that it will be more valuable in use immediately and in the future, and will cost much less to operate and maintain.

Cost Estimate

The detailed estimates given in full in Appendix F, are based on contractor's actual costs of similar work in New York City, and prices on similar work adjusted to meet the restrictions of the City ordinances. They are conservative and it is believed the contracts can be let well within these figures.

Estimated Time of Completion

In estimating the time of completion, see Appendix G, for rock excavation in shaft and tunnel within City limits, the fact that blasting is not allowed between sunset and sunrise was given full consideration.

Drilling in shafts in residential sections will in all probability not be permitted after 9 or 10 P. M. These conditions taken in connection with the eight-hour labor law, will cut down progress and enhance costs.

The progress assumed is based on actual performance of similar work in New York City.

Other Distribution Plans Considered

An estimate was made of the cost of a pressure tunnel to deliver 250 million gallons daily (see Appendix H), in view of the possible saving in postponing the distribution of the second 250 million gallons daily to some future time. The cost of the smaller tunnel was found, however, to be 76 per cent. of the cost of the 500 million gallons daily capacity tunnel.

Building at Intervals

The cost estimates given in Appendices H and I, indicate that a serious loss of money would be the result of attempting to provide for the distribution of the Catskill water-supply by installments of pressure tunnels or pipe-lines built at intervals of time, and providing at each time for the distribution of only a part of this supply.

Pipe Galleries

We have considered the suggestion that has been offered, from time to time, these twenty years, that subways for passenger travel, and 66-inch main conduits to convey water placed under about 300 feet pressure, could economically and with a proper degree of safety be carried in one and the same tunnel excavation. We advise against that mode of either subway or of water-supply construction, for reasons which we assume we need not at this time give in detail.

The Chief Engineer of the Public Service Commission for the First District of the State of New York writes us:

"The suggestion to use pipe galleries for steel pipe-lines 66 inches in diameter, carrying water under a pressure of 300 feet head, hardly seems feasible. These pipe lines would take up practically the entire gallery, and I might also add that this Department has found the difficulties in the construction of pipe galleries in connection with subway work so great that it considers them impracticable and hopes that they will ultimately be abandoned.

"I would suggest that the proposed pipe-lines be laid in streets where there are no subways, and that where they cross the proposed subway lines the locations should be taken up in detail with this Department, so that we can advise you as to the proper depth of the pipe lines at the sites proposed. These subway lines have not yet been designed, but I should be pleased to make a special study for you at such points as may be necessary."

Water Waste Prevention

One subject we have not yet touched upon is that of a future restriction of water waste throughout The City of New York, and whether it can be made to affect the conclusions we have reached.

This is a subject the treatment of which borders on the realms of prophecy.

If the government of the great City of New York through a series of years were a simple matter, it might be said, with some measure of certainty, what could and would be accomplished during any stated period as regards water waste prevention. But the course of future events in that line will be governed by a very complex combination of circumstances.

Individually, we thoroughly believe in the work of water waste prevention now conducted within the Department of Water Supply, Gas and Electricity, by able men, appointed with a view to having the desired results accomplished.

And doubt not that eventually waste will cease to run riot as it has in the long past of New York City; its water consumption attaining possibly the degree of good administration and of thrift which has for thirty years been exhibited by

Providence, R. I., a city of some 200,000 population (about 60 gallons per day per capita), and for shorter periods of time to an equal degree, or for the same length of time to a lesser degree (from 60 to say 100 gallons per day per capita), by many other American cities.

But this will not be accomplished without due and continued effort extending over years of time. Our inquiries on this subject lead us to the belief, in agreement with competent estimates that have been made, that to complete the work of inaugurating a thorough curtailment of water waste in New York City may, under favorable circumstances, require eight years.

Meantime, whatever happens, a proper and sufficient supply of water for fire and domestic purposes throughout The City of New York must at all times be furnished, and it is the duty of every one engaged in this incessant work, by the exercise of forethought, to see that nowhere and at no time shall there be an interruption to an adequate supply of water to the City, so vitally important to its welfare. We do not believe that considerations of an attainable reduction of water waste should be allowed to affect any of the work of water-supply now in progress or projected.

We have been greatly pleased—some of us have been agreeably surprised—at the extensive and able study that this project of a Manhattan pressure tunnel has already received. Besides replying to the specific questions put to us as we have done, we desire again to say that, whether viewed from the point of first cost, maintenance or of future cost, our opinion is that The City of New York will do well to direct the immediate construction of the proposed Manhattan pressure tunnel, for purposes of distributing the Catskill water-supply to the five Boroughs.

Respectfully submitted,

CLEMENS HERSCHEL,
Hydraulic Engineer.
FRANCIS L. PRUYN,
Consulting Engineer.
J. EDMUND WOODMAN,
Mining Geologist.

No. 2 Wall street, New York, May 14, 1910.

APPENDIX A

GENERAL DISCUSSION OF THE GEOLOGICAL PROBLEMS INVOLVED

I

Rocks Traversed by Proposed Line

At least five geological formations of different types are found along the line of the tunnel.

(1) Glacial and recent accumulations; boulders, gravels, clays, sand and river mud and silt; all unconsolidated. These will be met only in shafts.

(2) Manhattan schist, occupying most of Manhattan Island; chiefly mica schist with occasional coarse features.

(3) Inwood limestone, occupying certain lowlands. It is essentially a coarsely crystalline magnesian variety when pure, and becomes a schist with much mica when impure.

(4) Fordham gneiss, occupying much of The Bronx, and parts of southeastern Manhattan and western Queens and Brooklyn. It varies much from a fine schist to a coarse gneiss, and has in places a granitic phase (really a separate intrusive rock) called in subsequent pages a grano-diorite.

(5) Yonkers gneiss, found intrusive into the Fordham. A coarse gneiss of great strength.

These are folded, sometimes violently, into a series of north-northeast folds, that pitch more or less to the south.

General Description of Rocks Along Tunnel Line

Hill View reservoir is located in Yonkers gneiss. Thence from a downtake shaft the pressure tunnel starts southward, running approximately 8,400 feet in this rock. Passing to the Fordham gneiss across a contact which surface field evidence indicates will be sound, it traverses 21,190 feet of this rock to the margin of Harlem river and a contact with Inwood limestone. All this is under high land, in which numerous outcrops serve but to add to the testimony of the drill holes as to the soundness of the underlying rock. No cross-zones of deep decay, fracturing or faulting are known.

The breadth of Inwood limestone traversed under Harlem river is about 820 feet, all sound. The contact on the west side of the stream is between Inwood limestone and Manhattan schist, and according to the evidence of the drill-holes is thoroughly tight and firm.

From the crossing above mentioned, to approximately the corner of the Bowery and Delancey street, the tunnel passes uninterruptedly through this schist. The limestone of the Harlem valley runs south to 108th street, just west of Central park. West of this limestone the rock is schist and the land is high. It has been the evident aim in locating the tunnel line to run well within the latter, but to keep as far east as possible. It should be made certain that the line does not now lie in a contact zone, too close to the limestone.

At two points in the part of Manhattan now being discussed, cross valleys of weak rock have been encountered. One of these, Manhattanville, while being topographically low and showing deep glacial drift and deep decay in the bedrock below, is now known to have sufficiently good rock at the grade proposed for the tunnel at this point. But in order to meet the conditions the grade was depressed slightly, from 338 feet to 386 feet.

At the second point, the northwest corner of Central park, the tunnel turns along 106th street, from Columbus avenue, making its first cross-traverse in the schist. The line has been located so as to avoid most of the decay and disturbance; but it is possible that this has not been fully accomplished. The tunnel grade is raised to 153 feet under the worst part of the district, the rise starting at 121st street, immediately south of the Manhattanville disturbance. It seems certain that if the lower grade (approximately 385 feet) be maintained until Central Park is entered, or down to Shaft 12, good rock will be reached.

When it is considered that a deep grade has already been maintained from the Harlem River crossing to Morningside park, the additional expense of this prolongation of the deep grade will be almost negligible. The increase in security, on the other hand, will be great.

In the course of thus depressing the tunnel grade along 106th street, limestone may be met with; since a reef of this

rock pitches gently southward here, having the surface at 108th street. As this would involve the crossing of two more contacts and the traverse of a rock that should be avoided wherever possible, it may be found advisable to change the line slightly. Deeper holes along the latter will determine whether this is necessary.

The distance in Manhattan schist north of Delancey street is 49,860 feet.

The "lower east side section" is treated specifically in Appendix C. It is sufficient to say here that the traverse from the Bowery and Delancey street to the river at Clinton street is in slightly unsound rock for parts of the distance and it may be found advisable to depress the tunnel grade below 600 feet as at present located.

After entering Fordham gneiss unusually good rock is met to the uptake shaft (No. 23) in Brooklyn.

Proportions of Different Rocks Encountered

The four main varieties of bedrock will require tunnelling through approximately the following distances:

	Feet
Yonkers gneiss	8,400
Fordham gneiss	33,650
Manhattan schist	49,680
Inwood limestone	2,200
Total	93,930

Of this only 4,800 feet are cross-traverse excavation, the remaining being either on the strike of rocks or at a slight angle from it.

II

An answer to the question "Is the proposed Manhattan tunnel practicable from a geological standpoint?"

Dangers to Pressure Tunnels Due to Rock Condition

Taking the definition of a pressure tunnel given on page 60, it is evident that there are two classes of dangers that may be met in constructing and maintaining such a tunnel:

1. During construction.

2. During maintenance and subsequent to construction.

The character of the rock must be such that neither of these will be encountered to such degree as to endanger the structure, or the safety of human beings; nor on the other hand must such dangers greatly extend the time of construction or unduly augment the cost of construction or maintenance.

The dangers during construction are:

(a) Such inflow of ground-water or sea water, in amount or suddenness or both, as will either flood that part of the project or greatly increase its cost. With modern pumping methods the amount of water that can be handled is very large, before abandonment of an excavation becomes necessary. In our judgment there is not the slightest probability, even in the poorest ground thus far developed by boreholes, that abandonment of any section of the tunnel project will be necessary.

(b) Another danger is the caving or even inflow of soft material, so as to hinder or prevent work from being pushed to the stage of constructing the permanent lining. This will be considered below.

The dangers subsequent to construction are chiefly (1) outflow or leakage due to extreme porosity of the rock, which may occur without much regard to the differential of pressure between that exerted by the rock with its inclosed water and the outward pressure of the tunnel water; (2) inflow and mingling of water from without with that within the tunnel. These are both due in part to defective lining, and it is believed that the possibility of their occurrence can be neglected here, constructional care being depended upon to eliminate them.

The sources of danger from caving of material or from inflow of water are several:

(1) Rock Naturally Porous—The only variety met in this project that could be regarded as thus liable is the Inwood limestone. Limestones, on account of solubility, are frequently occupied by small or large cavities, ranging from almost microscopic size to caves. The Inwood formation contains so much magnesia as to be less easily soluble than most limestones; and the boreholes have shown it to be compact, firm and evenly crystalline—indeed, a superior rock when fresh.

(2) Contacts Between Rock Formations—Contacts between two dissimilar rocks are frequently weak, and it is not rare to find in regions of intense folding, as New York is, that slipping and other disturbances have taken place along these planes, which have later acted as underground water channels. Special attention appears to have been given this matter in exploration; and it has been proved that in no case is a contact *per se* likely to be a source of danger in the construction of this tunnel. Wherever contacts or immediately adjacent rock have been found in bad condition, there is seen to be a special reason for that state.

(3) Fracture and Fault Zones—In some cases both fractures and faults are tight enough to offer no trouble whatever at such depths as are reached by this tunnel. In others they are lines of subterranean water circulation to some extent. In that instance they may cause inconvenience and perhaps increase the cost of construction locally; but they do not commonly give such trouble as seriously to hinder work, unless it be where the fault is itself a zone of broken rock.

In such instances (a) fracture may be largely self-healing, plastic flow of the rock closing up all gaps. This is what has happened in the disturbed rocks along the northern division of the Catskill aqueduct, and is characteristic of clay rocks and some others of a similar type of plasticity. This most favorable state should not be expected uniformly in the rocks from Yonkers southward.

(b) The rock may remain open and a permanent and strong line of underground drainage be established. This is characteristic of brittle rocks, chiefly of coarse texture. It would probably not be found in the rocks under discussion.

(c) A state between these extremes may be found in which the fractures persist and decay may even affect their walls; but, on account of the physical nature of the rock or its minerals, waterflow along the disturbed zone is much impeded. It is believed that this is the condition obtaining at considerable depth in the more disturbed regions along the line of the pressure tunnel, notably at the northwest corner of Central park and in the lower east side district. Tunnelling should be entirely practicable through narrow belts of such rock, but with increased cost and slower progress.

(4) Rock weathering, which here takes the form chiefly of decay, with disintegration as a subordinate consequence. The zones of deep decay may be connected directly with fractures or faults, or may characterize a kind of rock or a particular situation. Of these we have several, confined, however, to two of the formations of the region—the Manhattan schist and the Inwood limestone.

What has been said immediately above applies here, as the state of the minerals is due to " weathering " in large part. The rocks, except the purer phases of the Inwood limestone, contain varying and sometimes large amounts of one or other variety of mica. The flaky character of this mineral diminishes the number of instances in which rock wounds heal completely, as in clay rocks, but the micas cause great obstruction to water passage.

Weathering consists in part in the formation of clay as a constituent of the rock, the loosening of the micas, with consequent weathering of the binder in the rock and frequently considerable disintegration. When carried far in broad belts, this would render the rock unfit for excavation at the depths contemplated here. But in the only two portions of the field where it is known at tunnel grade, it is believed that a deeper tunnel will entirely avoid the evil.

With respect to the injurious features discussed under the various headings above, the order of the rock, with the best rock first, is Yonkers gneiss, Fordham gneiss (these two about equal in quality), Manhattan schist, Inwood limestone.

(5) Soft spots or pockets. It is undeniable that in the Manhattan schist there are rare seams of soft material, chiefly micaceous. One such lens was encountered at the site of St. John's Cathedral; two were met in the subway at Park avenue, between 38th and 39th streets. All the cases of which we can obtain authentic record were comparatively shallow.

A number of such pockets are alleged to have been encountered entirely on the testimony of borings. Stories are told of the sudden dropping of drills many feet after passing hard rock. But it must be remembered that several causes may contribute to this apparent effect. In the first place, it has often happened that drills, after working laboriously and slowly in hard quartz and feldspar rocks for some time, may suddenly

encounter a band of soft but sound rock, highly micaceous in character, into which the bit, previously working under all the power possible from the particular machine, forces its way with great readiness. So sudden is the change that the drill appears to jump or fall. And if the soft band lies parallel to the axis of the drill, or vertical in most of the work done in New York, the bit may go for a long distance in such soft rock and apparently develop a great mass of it, while in reality there is but a narrow and harmless band.

A second cause is intentional or unintentional error in recording progress. In not a few instances, where proper care has not been taken in making records, it is found that several feet of progress are quite unaccounted for. The figures for the day must show the point attained at the end of work, so somewhere there must come a discrepancy, which can be best labelled as soft ground, or more likely a "cave."

Nevertheless, such soft spots may occur in rocks such as the schists and gneisses of New York. There is no way to prophesy their presence, short of sinking holes to grade, at intervals of every few feet—a manifest impracticability. It is only necessary to rest upon the undeniable fact that, in all the excavating work in this city, so few have ever been discovered and none have been met that proved unsurmountable barriers to completion of the work. In other words, the probability of encountering such pocket is so small as to be negligible. Should one be met, it can certainly be either penetrated or passed without taxing the engineering skill of to-day.

Location of Pressure Tunnels

It may be said that pressure tunnels can be constructed and maintained in almost any rock that has a fair degree of hardness, freshness, impermeability, freedom from faults and fractures.

Whereas, in New York City a number of rock formations are present, each different in some respects from the others, the following choice is worth making:

(1) Hard formations should be chosen rather than soft. The latter are subject both to deeper erosion and to deeper decay.

(2) Ridges should be followed rather than valleys. They are more likely to have a shallow zone of weathering, because the rock is so hard and resistant that it has thus been able to withstand the action of the elements.

(3) Dense formations should be chosen rather than permeable ones. It is but reasonable a rock which permits least water to pass through it is best adapted to excavation.

(4) As few contacts as possible should be crossed. While in individual cases contacts may be as favorable as the adjacent or any other rock, contacts are weak and permeable in so many instances that they are naturally regarded with suspicion.

(5) Contact zones should be avoided. They are often weak and subject both to mechanical shattering and to chemical decay, the whole end of which is to admit water.

(6) A sufficient rock cover should be provided in pressure tunnels. For the hydraulic conditions found in the plan under consideration, it is believed that at least 100 and preferably 150 feet of sound rock should overlay the tunnel.

Exploration of Rock

In our opinion the exploratory work has been unusually thorough. We know of no other large city area of difficult lithology and structure, the rocks of which have been studied with so great care or in such detail.

Stratified rocks may usually be assumed to change little along the strike for considerable distances. In this instance there is everywhere a gentle pitch southward, thus bringing new strata to the surface in this direction as well as east and west. And for this reason the sections brought up in successive drill holes along the general strike of the rocks vary somewhat. But the rocks are so persistent and similar in character for long distances north and south that unless for special reasons holes at shaft sites (4,000 feet apart) are often sufficient.

In exploring across the structure a different condition obtains. Here diverse layers are met in quick succession, and the holes may require to be close enough together to penetrate most or all of these layers.

Opinion

Our answer to the question "Is the proposed Manhattan tunnel practicable from a geological standpoint?" is that it is practicable, that it is superior to others originally contemplated through the same Boroughs, and that its location, both geographically and in depth, has followed quite adequate exploration, except in the few places indicated above.

III

Answer to the question, "Which, in your opinion, is the better route for a pressure tunnel, if constructed (a) from Hill View reservoir, through Queens to Brooklyn, or (b) from Hill View reservoir through Manhattan island to Brooklyn?"

We would unhesitatingly answer the latter, speaking from a geological standpoint. Our judgment from the engineering viewpoint is given in our report.

It is perhaps unfortunate that no drill holes have been sunk to test this route systematically; but it could hardly alter final judgment in the matter. The engineering evidence is so overwhelmingly in favor of carrying a pressure tunnel, if one be constructed, through Bronx and Manhattan, that only marked unsuitability of the rocks there, coupled with the presence of unusually favorable rock and structures along the line proposed through Queens to Brooklyn, could reverse the decision that the present route is the better of the two.

But the rock conditions, instead of being better along the pipe-line first proposed to Queens, are comparatively unfavorable. This much we know from surface field evidence, without waiting for borings: (1) The topography is less advantageous, indicating no lines of especially firm rock to be followed. (2) The presence of two deep valleys to be crossed adds no advantage to this route. (3) In the field the rocks are seen to be in a condition by no means so firm and fresh as those of western Bronx and Manhattan, which probably accounts in large measure for the low relief of the surface. (4) A far higher ratio of cross-cutting to drifting on the strike of the rock would be necessary, with its attendant uncertainties. (5) The crossing to Queens, wherever it might be, would be in unfavorable ground. A downfolded belt of Manhattan schist extends

southward from Morrisania, narrowing and steepening as it proceeds, and the tunnel would be obliged to pass for a considerable distance along or obliquely across this syncline. Again, a folded projection of Fordham gneiss encircled by Inwood limestone, lies on the east of this fold, and the tunnel must cross this area obliquely, including a submarine traverse several times as long as the proposed route under the lower part of East river. This is at the beginning of the disturbed zone that is met in the "lower east side section"; but at the north, it is nearly two miles across in the direction to be followed by the tunnel. (6) While the rock in the extreme western part of Long Island City is Fordham gneiss, it is not on the whole of quite so good quality as in The Bronx, being cut by many granite dikes. (7) The configuration of the rock floor made by the surface of the gneiss in Queens. Unconsolidated sands and clays of comparatively recent age cover the larger part of the gneiss, and the hard rock floor pitches rather rapidly down southeastward.

With a large number of doubtful or unfavorable points certain to be raised against the route as seen from even surface rock conditions, with an entire lack of detailed information of the character of the rock, such as drill-holes would furnish, it is our opinion that the idea of a pressure tunnel from Hill View to Queens and Brooklyn, crossing under the East river at its northern end, should not be given serious consideration at this time.

APPENDIX B

RESULTS OF ROCK BORINGS ALONG LINE OF PROPOSED TUNNEL

In the course of exploration for tunnel location diamond drill holes have been put down at all points where they were either essential or valuable for discovering the structure and condition of the rocks at and near the line of the tunnel. Some of these were comparatively shallow. In places where outcrops or other sources of information show sound rock at or close to the present surface of the ground it is obviously unnecessary to sink deep holes every few feet.

In two classes of situations, however, holes are required either to the proposed grade of the tunnel, or to such depth as proved conclusively the kind and condition of the rock. In a few sections these features were so little known at the beginning of the field work conducted by the Board of Water Supply, and the rock conditions were deemed so important in solving the problem of location, that unusually numerous borings were made, some shallow, some deep. Such districts were (1) the Harlem River crossing (in spite of information furnished by earlier tunnel construction); (2) from 126th street to 106th street, embracing Morningside park and the Manhattanville valley; (3) the "lower east side section," from Bowery and Delancey street to Clinton and Cherry streets; (4) East River crossing.

Of these (1) the Harlem River crossing proved to have so firm and fresh rock in the river bed that it was unnecessary to sink more than two holes to tunnel grade, in or close to the river. (2) The topography at the north end of Morningside park, and the topography and rock distribution at the south end and adjacent to the northwest corner of Central park, gave reasonable possibility of finding deep rock decay and cross faulting with crushing of the wall rock. Hence in both portions of that district several deep holes were sunk, with the result of finding sound rock at the place and depth proposed at the north end, and of indicating at the south end that the required conditions will be met by depressing the tunnel grade slightly. (3) The third district is still under investigation, and the conclusions reached by us from all the

evidence at present available are stated in detail elsewhere (Appendix C). It can be said here that it is the only section besides the above mentioned in which the tentative plans drawn up by the Board of Water Supply may require to be amended by reason of rock conditions. (4) The crossing of East river at the point proposed will not be accompanied by any of the uncertainties that exist in regard to the rocks beneath all portions of the river north of 17th street. For here the river is in Fordham gneiss, a rock of proved worth as ground for any excavation; while to the north faulted and shattered and decayed rocks occupy the river everywhere. The drill holes started in and adjacent to the river from the foot of Clinton street to Brooklyn discovered rock so sound and firm that deep drilling would have been superfluous.

Turning now to the details recorded in the form of drill cores, the following statement summarizes a complete study of all such throughout the line and a tabulation of the results.

From the downtake shaft at Hill View to Manhattanville the rock met at tunnel grade is sound, and the hight of good rock over the tunnel is adequate. This is equally true of all of the four geological formations traversed. At 125th street, where a deep cross-valley intersects the line of the tunnel, decay has proceeded to within 93 feet of the roof of the tunnel; but the latter itself would be excavated in sound schist.

The holes on 106th street show a zone of shattering and some decay, consequent upon the proximity of an anticline of limestone to the north, pitching southward underneath the schists cut along 106th street. Hole 60 shows rock that is alternately decayed and hard, but it would not be impossible to drive the tunnel through it.

From 106th street and Central park, sound rock and ample cover are found until the " lower east side section " is reached. The East River crossing and the course in Brooklyn are in good rock.

APPENDIX C

DISCUSSION OF THE GEOLOGY OF THE "LOWER EAST SIDE DISTRICT," WITH REFERENCE TO DEEP TUNNELLING

General Statement

From Hunt's point and eastern Mott Haven, southward across Randalls and Wards islands and along the submerged valley of East river, is a folded zone in which are involved the Fordham gneiss, Inwood limestone and Manhattan schist. The zone is broad in the north and folding less severe. Gradually the folds pinch closer as one proceeds southward, until where cut by the line of the proposed pressure tunnel the rocks are not only close folded, but crushed and faulted by breaks that strike nearly or quite parallel to the strata. With increased intensity of disturbance comes a decrease in the breadth of the poor ground, but an increase in the depth of the zone of decay. The breadth of ground regarded as in any way objectionable at the depth proposed is 4,000 feet between the extreme points, which distance includes much good rock, but in considering the zone across which there may be required a depression of the tunnel grade, it is necessary to include this in full.

The district is still under exploration. Its geology has been reported upon from time to time to the Board of Water Supply by its geologist. It is the aim of this appendix merely to discuss such features as have most immediate relation to the problem of cross-tunnelling through this section of the City. As will be seen below, they are the data that give ground for the opinion expressed at the end of this appendix.

The disturbed zone leaves East river along the water-front from the foot of 33rd street to that of 17th street (approximately), running thence southward and leaving the island along the water-front from Rutger's slip to approximately the foot of Wall street. East of this, Fordham gneiss extends across from Brooklyn, furnishing secure rock for excavation purposes.

While the structure is important, it is even more necessary in this connection to determine certain other features, in part connected with the structure. These are especially (1) the

total length of poor ground, (2) depth of decayed, shattered or otherwise permeable rock, location and dimensions of such rock as bids fair to create trouble in constructing or maintaining the tunnel.

In brief, the questions raised may be answered in part by saying (1) that for a short stretch the rock floor has been eroded to considerable depths, the overburden being uncompacted and pervious material, (2) that there are three lines, along which fracturing and probably faulting have occurred, nearly parallel with the strike of the formations, shattering the adjacent rock; (3) that as a result of this faulting and crushing, decay has proceeded locally to a great depth below bedrock surface.

It is found that the zones of crushing and decay are in the form of narrow wedges, thinning downward, ultimately to disappear. It is further established, by gross and microscopic examination of cores and rock samples, (a) that decay is subordinate to mechanical crushing; (b) that the individual zones of disturbances are narrow at tunnel grade, but are still to be detected in two cases; (c) that the condition of the rock, especially as seen under the microscope, indicates with certainty that within a slightly increased depth the rock will be found entirely sound.

Details of Holes

All the shallow holes of Delancey street show much decayed rock; but none extend far below 200 feet, and the proposed tunnel grade is 600 feet. This constitutes the western zone of disturbance. Three holes on Delancey street penetrating Fordham gneiss show sound rock below 150 feet.

The tunnel is planned to turn from Delancey street along Allen, so as to keep for as long a distance as possible in Fordham gneiss and still to reach the river by the shortest practicable route under the streets.

The second strip of bad ground is along Hester street, from Allen to Suffolk. But the thickness of sound rock above tunnel grade is ample except in Hole 202, on Hester street, west of Suffolk. The bottom of this, approximately at grade, is in fairly sound gneiss, which becomes broken upward and at 100 feet above the tunnel is badly weathered.

This hole is situated in the middle zone of crushing and decay. The rock is sound enough for tunnelling at the depth proposed for the tunnel, but gives little firm rock above it across one short stretch.

The third or eastern zone of disturbance is the most pronounced at tunnel grade. In Hole 207, on Henry street, between Montgomery and Clinton streets, the rock is badly weathered to 100 feet above grade. Thence downward it is broken considerably, but microscopic examination shows the minerals composing the rock to be fairly fresh. In Hole 211, on Clinton street, between Madison and Monroe streets, the bottom is in firm and tight Fordham gneiss, and for over 100 feet upward the rock is undecayed, but is broken considerably.

Microscopic Examination of Rock Cores

The solid core recovery from certain of the holes, in which decay seems to have gone on deepest, is not large in amount, and gives excuse for supposition that the rock may be widely decayed to great depths, especially along the shear zone met in Holes 207 and 211. But microscopic study of portions of the recovered core shows clearly that the chief action upon the rock has been a mechanical fracturing, decay being largely consequent upon it and both characterizing a narrow strip of ground and probably closely limited by it.

In Hole 207, from 532 feet to the bottom, the recovery was in short bits. In the slide the hornbend gneiss, which begins at 532 feet, is seen to be fractured, but not badly in detail. Its minerals are rather generally decayed and hydrated, especially at the margins of the pieces, but, while the rock would not furnish good working ground, it is by no means so bad as much rock that is met in deep excavations, as in mining.

In Hole 211, the rock, from 571 to 580 feet, examined microscopically, is found to be quite fresh and tight, slight decay of the edges of the feldspar pieces being the only evidence of change. Unless cut by pronounced rifts it should behave excellently in tunnelling.

Summary of Interpretation

For approximately 4,000 feet along the line as now laid down the tunnel must traverse a zone within the boundaries

of which, while there are sound bands, the rock is more or less sheared and crushed in three places. In two of these the disturbance is noticeable to at least the proposed tunnel grade.

The evidence shows plainly that these disturbed zones are narrow and sharply defined, but that they are separated by much sound rock. The opinion is further justified by field evidence that the zones are narrowing downward and should disappear shortly below.

Such information as can be had does not favor shifting the line of crossing of this zone to points north or south, in the hope of easement of the engineering difficulties. The ground for miles up East river is of the same general character, and the distance to be crossed in any traverse made to the north is greater.

It remains, therefore, to make a tentative decision (1) whether the tunnel is practicable along the course and at the depth proposed; (2) if not, whether altering the grade of the tunnel in this section would render the route practicable; (3) whether, if the present plan be feasible, changing the grade of the tunnel in this section would be advantageous from the standpoints of time of completion, cost, safety of construction and permanence.

Opinion

With regard to (1) it is our opinion that the tunnel can be constructed along the course and at the depth proposed. This also disposes of point (2).

The last question brought up is easy to answer. It is undeniable that at the proposed tunnel grade there will not be at all points the 100 or 150 feet of sound rock overhead that is desired. The poor ground could, in our opinion, be traversed safely, even if special reinforcement were necessary. But the increased cost and the uncertainty of permanence must be weighed against such increase in cost and in time of completion as will result from a depression of the tunnel grade.

APPENDIX D

PRESSURE TUNNEL PLAN TO DELIVER 500 MILLION GALLONS DAILY FROM HILL VIEW RESERVOIR, AS RECOMMENDED IN REPORT OF BOARD OF WATER SUPPLY TO THE BOARD OF ESTIMATE AND APPORTIONMENT, DATED NOVEMBER 15, 1909

Historical

In the report of the Board of Water Supply dated October 9, 1905, to the Board of Estimate and Apportionment, a summary is given of the proposed system to obtain a supply of water from the Catskills of 500 M. G. D. In this report provisions were made for supplying Brooklyn with 100 M. G. D. and Richmond with 20 M. G. D. The distribution of the remaining 380 M. G. D. was left for future consideration.

The plan proposed a steel pipe-line from the Hill View reservoir to the East river, a 10-foot tunnel under the East river at Port Morris to Long Island, and a steel pipe-line connecting the tunnel to Forest park, in Brooklyn.

A cast-iron pipe-line was to extend also from the tunnel to the Narrows, passing under them to Richmond. The cost of this work was estimated at $10,224,000.

A reservoir was proposed at Forest park, Brooklyn, but no provision was made for it in the estimate. No provision was made for a reservoir in Richmond, made necessary for this plan, nor were pipe-lines provided for a distribution of the 100 M. G. D. from Forest park to Brooklyn.

To provide for these reservoirs and distributing pipe-lines would cost approximately $5,000,000, which, added to the original estimate of $10,224,000, makes $15,000,000, the cost of delivering 120 M. G. D., or about one-quarter of the Catskill supply.

The location of this system is indicated in brown on Sheet 4, Accession 6663. The time of completion would be about five years, owing to the length of the Port Morris tunnel crossing under the East river and the preliminary investigation necessary before the letting of contracts.

To complete this preliminary work, and in place of it to provide in a studied and best manner for the permanent

distribution needs of the City, the Board of Water Supply, by its letter of November 15, 1909, proposed the work which is the subject of the estimates herewith presented. This letter is based on the report of the Chief Engineer of the Board of Water Supply of November 1, 1909.

Under date of December 8, 1909, the majority of a committee consisting of the Chief Engineer of the Department of Finance, the Chief Engineer of the Board of Estimate and Apportionment, the Chief Engineer of the Board of Water Supply and Assemblyman Lindon Bates, Jr., reported to the Board of Estimate and Apportionment; while the report of the minority, consisting of Assemblyman Lindon Bates, Jr., was presented December 10, 1909.

Under date of February 2, 1910, the Chief Engineer of the Department of Water Supply, Gas and Electricity reported on this same project to the Honorable Commissioner of the Department of Water Supply, Gas and Electricity.

As stated in the beginning of the main report, of which this is Appendix D, the present Commission of two engineers and a geologist was appointed by letters from a Committee of the Board of Estimate and Apportionment, appointed March 4, 1910.

Estimate

The plan here considered for the delivery of water to all the Boroughs calls for a pressure tunnel, situated at least 150 feet below the surface of the "rock floor." Starting from Hill View reservoir, to pass under the Harlem river, near High Bridge, thence extending under the west side of Manhattan to Central park, thence under Central park and the centre of Manhattan to Delancey street, crossing under the East river to Brooklyn, and terminating near Flatbush and Lafayette avenues.

From this point a 66-inch steel pipe extends to Fifth and Prospect avenues, whence a 48-inch cast-iron pipe is employed to 79th street and the Narrows.

A 36-inch flexible joint pipe is used under the Narrows to Richmond, where a 36-inch cast-iron pipe delivers to a reservoir at Silver lake, at an elevation of 225 feet.

The line to Queens consists of a 66-inch steel pipe from the end of the tunnel to Willoughby and Carlton avenues, then

reducing to a 48-inch cast-iron pipe, extending to Thompson and Fisk avenues.

The size and length of tunnel and pipe-line under this system are as follows:

PRESSURE TUNNEL

Limits of Section	Size of Tunnel		Length in Miles
	Feet	Inches	
Hill View reservoir to City line	16	7	.40
City line to 135th street	15	..	7.31
135th street to 40th street	14	..	4.94
40th street to 24th street	13	..	.40
24th street to Delancey and Allen streets	12	..	1.36
Allen and Delancey streets to Flatbush avenue and Lafayette avenue, Brooklyn	11	..	3.24

PIPE-LINES

Limits of Section	Size of Pipes	Length in Miles
QUEENS LINE		
Tunnel terminal to Carlton and Willoughby avenues	66-inch steel	.69
Willoughby to Fisk and Thompson avenues	48-inch cast iron	7.99
RICHMOND LINE		
Tunnel terminal to Fifth and Prospect avenues	66-inch steel	1.72
Prospect avenue to Narrows	48-inch cast iron	3.51
Crossing the Narrows	36-inch submerged	1.88
Narrows to Silver Lake reservoir	36-inch cast iron	1.70

The construction shafts are located approximately 4,000 feet apart and will be used as uptakes from which, in an emergency, the entire supply for any Borough can be supplied.

The large-sized tunnel goes to the 135th street uptake shaft, so that the present Croton tunnel can be put out of service for cleaning or repairs if desired, and the supply furnished through the new tunnel.

Three hundred million gallons daily can be delivered to Brooklyn with a frictional loss of 3 feet per mile, and the tunnel is of sufficient size to deliver the full 500,000,000 gallons daily with an additional loss of about 15 per cent.

The following pressure will be available in the different boroughs:

Boroughs	250 Million Gallons Daily	500 Million Gallons Daily
	Feet	Feet
The Bronx	290	285
Upper Manhattan	283	275
Lower Manhattan	280	270
Brooklyn	280	265
Queens	265	245
Richmond	260	225

At each uptake automatic pressure controlling-valves will regulate the pressure delivery as deemed advisable, and no changes in the distributing systems will be made necessary.

The estimated time of completion is four and one-quarter years for this plan, at a cost of $26,000,000.

A detailed estimate of cost is as follows:

Cost Estimate of City Aqueduct Pressure Tunnels to Deliver 500,000,000 Gallons Daily

Cost per linear foot of tunnel

Diameter	Length Feet	Tunnel	Shaft	Total	Total Cost
16 feet 7 inches	2,112	$187.47	$34.40	$221.87	$467,589.00
15 feet	38,597	162.37	34.40	196.77	7,594,732.00
14 feet	26,083	150.27	34.40	184.67	4,816,747.00
13 feet	2,112	139.97	34.40	174.37	368,269.00
12 feet	7,181	122.77	34.40	157.17	1,128,638.00
11 feet	17,107	113.37	34.40	147.77	2,527,901.00
Total					**$16,904,876.00**
Easements, right-of-way, etc.					150,000.00
7 shaft sites at $100,000					700,000.00
2 drainage shafts					250,000.00
					$18,003,876.00
Twenty per cent. for engineering and contingencies					3,600,000.00
Cost of pressure tunnels					**$21,605,000.00**

Pipe-lines in extension of pressure tunnels

Size	Length in Miles	Cost Per Mile	Total
66-inch steel	2.4	$173,000.00	$415,000.00
48-inch cast iron	11.6	143,000.00	1,659,000.00
36-inch cast iron	1.7	110,000.00	187,000.00
36-inch submerged	2.0	275,000.00	550,000.00
			$2,811,000.00
Twenty per cent. for engineering and contingencies			562,000.00
			$3,373,000.00

Distribution reservoir in the borough of Richmond

Reservoir in Richmond, 400,000,000 gallons daily capacity	$750,000.00
Land	300,000.00
	$1,050,000.00
Twenty per cent. for engineering and contingencies	210,000.00
	$1,260,000.00
Grand total	**$26,238,000.00**
Say $26,000,000.	

APPENDIX E

PIPE-LINE TO DELIVER 500,000,000 GALLONS DAILY —AN ALTERNATE PLAN PROPOSED BY THE BOARD OF WATER SUPPLY IN THEIR REPORT OF NOVEMBER 15, 1909

This plan substitutes pipes to deliver 500,000,000 gallons daily in place of tunnels as in other plan, delivery to be made at the same pressure.

The largest pipe that can be used, owing to the difficulties of placing among existing subsurface structures, is a 66-inch.

A 10-foot tunnel crosses under the Harlem river to deliver the Manhattan supply and under the East river to supply from The Bronx to Queens and Brooklyn. An 8-foot tunnel extends under the East river to cross-connect lower Manhattan with Brooklyn.

Sixteen 66-inch pipes lead from Hill View reservoir; seven extend to Manhattan, and seven to Long Island, leaving two for The Bronx supply.

The life of steel pipes is estimated at thirty-five years, after which time they would have to be renewed. The interference with business in laying these large pipes would be considerable and the interference with subsurface structures present and to come, especially subways, would be great.

It is estimated that this system can be completed in from four to five years, the controlling factor being the long tunnel under the East river, near Port Morris. No diamond drill borings have been made to date on the line of this tunnel.

The detailed cost estimate of this system is given below. The total is approximately $47,000,000, or almost double that of the pressure tunnel, giving an equal hydraulic service. Even with making due allowance for possible deferment of installation of pipe-lines, since all of them would not be required immediately, the "present worth" of the pipe-line system is greater by $10,000,000 than the pressure tunnel.

ESTIMATED COST OF PIPE-LINE TO DELIVER 500,000,000 GALLONS DAILY

Size of Pipe	Length Miles	Cost Per Mile	Total Cost	
Pipe Lines				
Steel pipe, 66-inch, Manhattan.	44.5	$209,000.00	$9,300,000.00	
Steel pipe, 66-inch.....	166.0	173,000.00	28,718,000.00	
Steel pipe, 66-inch, submerged..	0.3	350,000.00	105,000.00	
Cast-iron pipe, 48-inch.....	3.8	143,000.00	543,000.00	
Cast-iron pipe, 36-inch	1.7	100,000.00	170,000.00	
Pipe, 36-inch, submerged.....	2.0	250,000.00	500,000.00	
			$39,336,000.00	
Fifteen per cent. for engineering and contingencies.....	....	.....	5,900,000.00	**$45,236,000.00**
Size of Tunnel	**Length Miles**	**Cost Per Mile**	**Total Cost**	
Pressure Tunnel				
10-foot tunnel.....	0.8	$1,000,000.00	$800,000.00	
8-foot tunnel	0.5	900,000.00	450,000.00	
Easements and right-of-way....	....	.....	50,000.00	
			$1,300,000.00	
Twenty per cent. for engineering and contingencies.....	....	.....	260,000.00	**1,560,000.00**
Grand total.....				**$46,796,000.00**

APPENDIX F

DETAILED COSTS OF (1) PRESSURE TUNNELS, 8 FEET TO 16 FEET 7 INCHES DIAMETER, (2) PIPE, 66-INCH STEEL AND 48-INCH CAST-IRON, (3) SHAFTS

ESTIMATED TUNNEL PRICES PER LINEAR FOOT FOR CITY PRESSURE TUNNELS

	Diameter								
	16 ft. 7 in.	15 ft.	14 ft.	13 ft.	12 ft.	11 ft.	10 ft.	9 ft.	8 ft.
Excavation	$117.00	$96.30	$86.40	$78.30	$66.60	$59.40	$49.00	$39.93	$31.90
Trimming	2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.16
Concrete	48.40	44.00	41.80	39.60	34.10	31.90	28.53	26.60	23.63
Grouting	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75
Temporary timber	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Steel lining	.36	.36	.36	.36	.36	.36	.36	.36	.36
Dry packing	.80	.80	.80	.80	.80	.80	.80	.80	.80
Pumping	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Testing	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Total cost, tunnel	$187.47	$162.37	$150.27	$139.97	$122.77	$113.37	$99.60	$88.60	$77.60
Total cost, shaft	34.40	34.40	34.40	34.40	34.40	34.40	34.40	34.40	34.40
Total cost	$221.87	$196.77	$184.67	$174.37	$157.17	$147.77	$134.00	$123.00	$112.00

ESTIMATED COST OF SHAFT SINKING FOR CITY AQUEDUCT TUNNELS

Labor, per shift		$100.00
Plant, power and overhead charges		40.00
Total cost per shift		$140.00
Working two shifts only and with progress of 35 feet per month (per foot of shaft)	$210.00	
Powder	8.00	
Timbering	15.00	
Disposal	12.00	
	$245.00	
Contractor's profit, contingencies, etc.	55.00	
		$300.00
Concrete plug, 175 feet long (per foot of shaft)	$40.70	
Concrete lining	16.30	
Chamber	5.20	
Valves and regulators	7.50	
Uptake pipe, mortar lined	7.30	
Bronze cut-off valve	58.00	
		135.00
Total costs of shafts per linear foot		$435.00

Average depth of 23 shafts, 320 feet.
Length of tunnel, 93,112 feet.
Cost of shafts per linear foot of tunnel, $34.40.

DETAILED ESTIMATE OF COST OF 66-INCH STEEL AND 48-INCH CAST-IRON PIPE

	Cost Per Linear Foot	
	66-inch Steel	48-inch Cast-iron
Pipe delivered	$17.00	$14.00
Special structures	1.00	.55
Excavation, earth	1.55	1.05
Sheeting and bracing	2.52	2.50
Substructures	2.25	1.00
Laying	.75	1.50
Disposal	.85	.47
Back-fill	.50	.30
Pavement replacing	3.00	2.20
Total	$29.42	$23.57
Fifteen per cent. engineering and contingencies	3.41	3.54
Total cost per linear foot	$32.83	$27.11

The above are average prices for The Bronx, Brooklyn and Queens.

For Manhattan the average excavation would be about one-half rock and prices would be:

	66-inch Steel	48-inch Cast-iron
Average as above	$32.83	$27.11
Add for one-half rock, etc.	6.77	3.49
Total cost per linear foot	$39.60	$30.60

APPENDIX G

PROGRESS IN TUNNELS AND SHAFTS IN PREVIOUS SIMILAR WORK—PROGRESS ASSUMED FOR THIS REPORT— TIME OF COMPLETION OF PRESSURE TUNNELS

Shaft Progress

Average monthly progress from start to finish:
Wallkill, 6 shafts, 67.5 feet per month.
Moodna, 3 shafts, 66.6 feet per month.
Rondout, 8 shafts, 63 feet per month.

New York Subway—Notes by Mr. Deyo

104th street, 52 feet deep; average progress, 26 feet per month.

167th street, 91 feet deep; average progress, 23 feet per month.

181st street, 110 feet deep; average progress, 22 feet per month.

181st street, 158 feet deep; average progress, 45 feet per month.

Tunnel Progress

Rondout pressure tunnel, average progress, 207 feet per month.

Wallkill pressure tunnel, average progress, 230 feet per month.

Pennsylvania crosstown tunnels, average progress, 180 feet per month.

Sewer tunnel, Yonkers, average progress, 200 feet per month.

Assumptions for This Report

Sinking shaft, 35 feet per month.
Driving tunnel, 150 feet per month.
Concreting tunnel, 300 feet per month.

Progress

Work within the City limits cannot be prosecuted as advantageously as in open country. The City ordinances prohibit blasting between sunset and sunrise. This interferes mate-

rially with progress. In shaft sinking it means one idle shift per day. In residential districts it is doubtful if drilling in shafts can be done after 11 P. M.

Time for Completion of Controlling Sections of Tunnels for City Aqueducts

CRITICAL SHAFTS

No. 7, 380 feet deep, Sedgwick avenue; No. 8, 355 feet deep, Speedway; No. 9, 430 feet deep, Colonial park, residential; No. 10, 400 feet deep, St. Nicholas park, residential; No. 11, 400 feet deep, Morningside park, residential; No. 20, 650 feet deep, Allen and Delancey streets, residential; No. 21, 650 feet deep, East river.

SHAFT NO. 7

Preparation of contract, 6 months; time of awarding contract, 2 months; assembling plant, 2 months; sinking shaft 380 feet, 11 months; driving 2,600 feet of tunnel, 17.4 months; concreting 2,600 feet of tunnel, 8.6 months; refilling and grouting shaft, 2 months. Total, 49 months, or 4¼ years.

SHAFT NO. 9

Preparation of contract, 6 months; awarding contract, 2 months; assembling plant, 2 months; sinking shaft 430 feet, 12.3 months; driving 2,000 feet of tunnel, 13.3 months; concreting 2,000 feet of tunnel, 6.7 months; refilling and grouting shaft, 2 months. Total, 44.3 months, or 4 years.

SHAFT NO. 20

Preparing contract, 6 months; awarding contract, 2 months; assembling plant, 2 months; sinking shaft 650 feet, 18.7 months; driving 2,000 feet of tunnel, 13.3 months; concreting 2,000 feet of tunnel, 6.7 months; refilling and grouting shaft, 2 months. Total, 50.7 months, or 4¼ years.

APPENDIX H

COMPARATIVE COST OF PRESSURE TUNNELS TO DELIVER 500,000,000 GALLONS DAILY AND 250,000,000 GALLONS DAILY FROM THE HILL VIEW RESERVOIR THROUGH THE BRONX AND MANHATTAN TO BROOKLYN

PRESSURE TUNNEL OF 500,000,000 GALLONS DAILY CAPACITY

Size of Tunnel	Length Miles	Cost Per Mile	Total Cost
16 feet 7 inches	0.40	$1,171,000.00	$468,000.00
15 feet	7.31	1,039,000.00	7,595,000.00
14 feet	4.94	975,000.00	4,816,000.00
13 feet	0.40	921,000.00	368,000.00
12 feet	1.36	830,000.00	1,129,000.00
11 feet	3.24	780,000.00	2,527,000.00
			$16,903,000.00
Easements and right-of-way			150,000.00
Seven shaft sites at $100,000			700,000.00
Two drainage shafts			250,000.00
			$18,003,000.00
Twenty per cent. for engineering and contingencies			3,601,000.00
Total			**$21,604,000.00**

PRESSURE TUNNEL OF 250,000,000 GALLONS DAILY CAPACITY

Size of Tunnel	Length Miles	Cost Per Mile	Total Cost
11 feet	7.72	$780,000.00	$6,022,000.00
10 feet	4.94	710,000.00	3,507,000.00
9 feet	1.76	650,000.00	1,144,000.00
8 feet	3.23	600,000.00	1,938,000.00
			$12,611,000.00
Easements and right-of-way			150,000.00
Two drainage shafts			250,000.00
Seven shaft sites at $100,000			700,000.00
			$13,711,000.00
Twenty per cent. for engineering and contingencies			2,742,000.00
Total			**$16,453,000.00**

—equals 76 per cent. of cost of 500,000,000 gallons daily tunnel.

The line followed by these two tunnels is the same as shown on Sheet 4, Accession 6663.

APPENDIX I

PIPE-LINE SYSTEM TO DELIVER 250,000,000 GALLONS DAILY, OR THE FIRST INSTALLMENT OF THE CATSKILL WATER SUPPLY

This system provides for eight 66-inch steel pipes extending from Hill View reservoir into The Bronx. Three lines of pipe are carried into Manhattan, using submerged pipe-lines under the Harlem river, and three extending to Queens by means of an 8-foot tunnel under the East river, near Port Morris. (See Sheet 4, Accession 6663.)

Pipe-lines are provided in Manhattan so as to distribute to the high and low pressure service.

In Queens and Brooklyn, pipe-lines are extended to points where the supply is needed, and a line is also carried through Brooklyn and under the Narrows to Richmond.

The same loss of head would take place as in the tunnel system.

No tunnel is provided to cross-connect the Brooklyn and Manhattan supplies.

The time of completion of this system would be about five years owing to the long tunnel under the East river at Port Morris and to the fact that the preliminary investigations of this tunnel site would have to be made. The estimated cost is shown below and indicates that the expense of this system is within $1,600,000 of the pressure tunnel of twice the capacity.

ESTIMATED COST OF PIPE-LINE SYSTEM TO DELIVER 250,000,000 GALLONS DAILY TO THE BRONX, QUEENS, BROOKLYN AND RICHMOND

MAXIMUM SIZE OF PIPE, 66 INCHES

SIZE OF PIPE	LENGTH MILES	COST PER MILE	TOTAL COST
66-inch steel	82.0	$173,000.00 209,000.00	$14,810,000.00
48-inch cast iron	20.0	132,000.00 162,000.00	3,000,000.00
36-inch cast iron	4.0	100,000.00	400,000.00
66-inch, submerged	0.5	350,000.00	175,000.00
36-inch, submerged	2.0	250,000.00	500,000.00
			$18,885,000.00
Twenty per cent. for engineering and contingencies			3,777,000.00
			$22,662,000.00

PRESSURE TUNNEL

Size of Tunnel	Length Miles	Cost Per Mile	Total Cost
8 feet	0.5	$900,000.00	$450,000.00
Twenty per cent. for engineering and contingencies			90,000.00
			$540,000.00

RESERVOIR

One reservoir in Richmond, 400,000,000 gallons daily capacity	$750,000.00
Land	300,000.00
	$1,050,000.00
Twenty per cent. for engineering and contingencies	210,000.00
	$1,260,000.00
Total cost	**$24,462,000.00**

REPORT OF COMMITTEE OF BOARD OF ESTIMATE AND APPORTIONMENT

June 27, 1910.

To the Honorable the Board of Estimate and Apportionment:

SIRS—At the meeting of the Board of Estimate and Apportionment held on March 4, 1910, a Committee, consisting of the President of the Board of Aldermen, the Comptroller and the President of the Borough of Manhattan, was appointed to consider the plans of the Board of Water Supply for the construction of a pressure tunnel from the proposed Hill View Reservoir, passing through the Borough of The Bronx, under the westerly and middle portions of Manhattan Island and under the East River to the Borough of Brooklyn, and the said Committee was authorized to retain as expert advisers two engineers and a geologist, and it was requested to report to the Board its conclusions as to the feasibility of the project.

Your Committee begs to report that, in accordance with the authority conferred upon it, it retained Mr. Clemens Herschel, hydraulic engineer; Mr. Francis L. Pruyn, consulting and contracting engineer, and Mr. J. Edmund Woodman, mining geologist. These experts were instructed to advise your Committee upon the following points:

(1) Is the proposed tunnel practical from an engineering and geological standpoint?

(2) How does the estimated and probable first cost of this tunnel compare with (a) the estimated and probable first cost of a pipe-line from Hill View Reservoir through the Borough of Queens to Brooklyn, and (b) a pressure tunnel from Hill View Reservoir through the Borough of Queens to Brooklyn?

(3) Which is the better route for a pressure tunnel, if constructed, from Hill View Reservoir through Queens to Brooklyn, or from Hill View Reservoir through Manhattan Island to Brooklyn?

This Committee of experts, after a careful investigation, has submitted to us a report reviewing the entire project and containing a comparison of the cost of the pressure tunnel under Manhattan Island with the cost of pipe lines, and of a pressure tunnel through the Borough of Queens, and have

given the following answers to the questions submitted to them:

(1) The proposed Manhattan tunnel is practicable from an engineering and geological standpoint.

(2) The estimated and probable cost of the Manhattan pressure tunnel is $26,000,000, and it will require about four and a quarter years for its construction, while an equivalent pipe line system is estimated to cost $47,000,000 and to require about four and a half years for its construction.

Owing to the fact that no borings have yet been made on the line of a pressure tunnel through the Borough of Queens to Brooklyn, and owing to lack of detailed information as to the conditions which would be encountered, comparative estimate of the cost of a pressure tunnel through the Borough of Manhattan to Brooklyn and one by way of the Borough of Queens to Brooklyn can scarcely be made, but it is believed that under equally feasible conditions the Manhattan tunnel would cost less; that it is capable of supplying all five Boroughs; and that it would not need to be supplemented by a separate and special pipe line supplying the Borough of Manhattan and a cross-connection between Brooklyn and Manhattan.

The reply to the third question has already been given in the replies to Question No. 2, namely, that the route by way of Manhattan is better than that by way of the Borough of Queens for a pressure tunnel.

After receiving the report of the experts, your Committee on June 7, 1910, gave a public hearing to all who wished to favor or oppose the plan of the Board of Water Supply, and has also received some briefs accompanied by reports.

In view of all that has been said and written upon this subject, it seems scarcely necessary for the Committee to review the various arguments which have been presented. Those opposing the plan contend that its cost will be unnecessarily great, that sufficient information has not been secured, that the estimates of cost are unsatisfactory and unreliable, as are also the estimates of the future need of water by The City of New York, while one of the briefs submitted to us suggests a substitute plan by a tunnel crossing the East River by way of Rikers Island, a plan which it is estimated by those present-

ing it will cost but $18,500,000, while they predict that to carry out the plan of the Board of Water Supply will probably cost $56,000,000. These estimates appear to be based wholly upon speculation with respect to the geological formation, and do not seem to be predicated upon any accurate information or scientific investigation.

As to the estimates of cost, your Committee sees no reason to doubt the reliability of the estimates prepared by the Board of Water Supply and confirmed by the experts retained by us. Our confidence in the reliability of these estimates is strengthened by the fact that the cost of the work thus far done and contracted for by the Board of Water Supply has in almost every instance agreed closely with the estimates made by the Engineers of that Board.

As to the alleged insufficiency of information which has been secured, your Committee believes that the preliminary investigation has been unusually thorough, and can recall but few great public undertakings which have been characterized by such thorough and painstaking preliminary study as the project under discussion.

As to the estimates of the future needs of The City of New York, they are not the guesses of enthusiasts, but are based upon years of careful observation and intelligent compilation of statistics, which can lead to but one conclusion, and that is, that the Croton watershed has been developed to its ultimate capacity, and it is only by reason of the fact that the rainfall for a term of years has been above the normal that the City has not already seriously felt the need of an increased supply of water.

It has been urged that there is no occasion for hasty action, and that no harm will be done if approval of the plans is deferred for the present or until such further investigations can be made as will unquestionably establish the practicability of the project. We believe, however, that it would be most unwise to postpone action, as it is expected that in about three years we will have an aqueduct to Hill View Reservoir ready for the delivery of water, and if at that time there are no means of distributing it, the City will be unable to avail itself of the large expenditure which it has made in bringing this additional supply to the City limits.

In conclusion, your Committee is impressed with the fact that in scientific authority, in the reliability of experienced engineers and contractors, in careful and unprejudiced analysis, and in ordinary common sense, the weight of the arguments we have received is overwhelmingly in favor of the soundness and economy of the plan of the Board of Water Supply, and we would recommend that the Board approve of the plan and profile of the Board of Water Supply dated November 15, 1909, that it direct the Comptroller to issue corporate stock of The City of New York to an amount not exceeding $25,000,000 to meet the expense of carrying out the plan, that the resolution of this Board of January 7, 1910, requesting the State Water Supply Commission to suspend action on the said plans, be rescinded, and that the State Water Supply Commission be notified of this action. A resolution to this effect is herewith submitted. Respectfully,

WM. A. PRENDERGAST,
Comptroller.
JOHN PURROY MITCHEL,
President, Board of Aldermen.
GEORGE McANENY,
President, Borough of Manhattan.

BOARD OF ESTIMATE AND APPORTIONMENT CITY OF NEW YORK

The following was then offered:

Whereas, The Board of Estimate and Apportionment did, on December 10, 1909, authorize a modification of the general plan of the Board of Water Supply, said modification contemplating the construction of a pressure tunnel under Manhattan Island, from Hill View Reservoir to the Borough of Brooklyn, and by pipe lines leading thence to the Boroughs of Queens and Richmond; and

Whereas, The Board of Estimate and Apportionment did, by resolution of December 10, 1909, pursuant to Chapter 56 of the Laws of 1909, being Chapter 54 of the Consolidated Laws, known as the "State Board and Commission Law," request the State Water Supply Commission as speedily as possible to approve the said modification of the general plan of the Board of Water Supply; and

Whereas, The Board of Estimate and Apportionment did, by resolution of January 7, 1910, request the State Water Supply Commission to suspend action for approval of this modification until an opportunity might have been had for examination into the merits of the plan; and

Whereas, The Board of Estimate and Apportionment did, by resolution on the 4th day of March, 1910, approve the appointment of a committee of three with instructions to retain as expert advisers two engineers and a geologist, and the said committee was further instructed to examine into the engineering feasibility of the proposed pressure tunnel, and did report thereon at the earliest possible moment; and

Whereas, In pursuance of the resolution of March 4, 1910, a committee consisting of the Comptroller, the President of the Board of Aldermen and the President of the Borough of Manhattan was appointed and did engage the services of two expert engineers and a geologist, and did examine into the engineering feasibility of the proposed pressure tunnel, and did also at 8.30 o'clock on the evening of June 7, 1910, hold, after due advertisement, at the City Hall, a public hearing, at which many were heard in opposition to the plan and also many in favor thereof; and

Whereas, The said Committee did, on July 1, 1910, report in favor of the modification and recommend that the plan be proceeded with; now therefore be it

Resolved, That the Board of Estimate and Apportionment does hereby approve and adopt said report, map, plan and profile of the Board of Water Supply, dated November 15, 1909, and hereby declares the same to be the final map, plan or plans, and profile approved and adopted by the Board of Estimate and Apportionment, pursuant to the provisions of Chapter 724 of the Laws of 1905, as amended, and that in order to permit the carrying out of this plan, the Comptroller is directed to issue corporate stock of The City of New York in the manner provided by Section 169 of the Greater New York Charter to an amount not exceeding twenty-five million dollars ($25,000,000), the proceeds whereof to be applied to the uses and purposes of the Board of Water Supply; and be it further

Resolved, That the resolution of this Board dated January 7, 1910, requesting the State Water Supply Commission to suspend action on the contemplated modification of the general plan of the Board of Water Supply, as set forth in the resolution of December 10, 1909, of the former Board of Estimate and Apportionment be now rescinded, and that the State Water Supply Commission be so notified.

Which was adopted by the following vote:

Affirmative—The Mayor, the Comptroller, the President of the Board of Aldermen and the Presidents of the Boroughs of Manhattan, Brooklyn, The Bronx, Queens and Richmond —16.

I hereby certify that the foregoing is a true copy of a resolution adopted by the Board of Estimate and Apportionment at the meeting of said Board, held on the 1st day of July, 1910.

JOSEPH HAAG,
Secretary.

STATE OF NEW YORK
STATE WATER SUPPLY COMMISSION

In the Matter of the Application

of

THE CITY OF NEW YORK to the State Water Supply Commission for the approval of the report of the Board of Water Supply of The City of New York to the Board of Estimate and Apportionment of The City of New York, dated November 15, 1909, recommending modification of the map, plan and profile, dated October 9, 1905, approved by said Commission May 14, 1906, which modification is dated November 15, 1909, and is entitled "Board of Water Supply of The City of New York. Map and profile showing manner of delivering the water to the several Boroughs."

Decision

On December 16, 1909, the petition in the aforesaid matter was duly filed with this Commission. The Commission caused public notice to be given as provided by law that on the twelfth day of January, 1910, the Commission would conduct a public hearing thereon at the office of the Board of Water Supply of The City of New York. Pursuant to such notice duly given, the Commission met at the office of the Board of Water Supply, 299 Broadway, New York City, for the purpose of such a hearing, noted the appearances, and received in evidence such documentary evidence as the applicant offered.

The Board of Estimate and Apportionment of The City of New York, by its resolution bearing date January 7, 1910, requested this Commission "to defer final action on any projected extensions or modifications of New York's water supply system." In compliance with this request and upon motion of the Corporation Counsel for the petitioner, the proceedings were adjourned from time to time and until July 13, 1910, prior to which last named date, and on July 1, 1910,

the said Board of Estimate and Apportionment of The City of New York rescinded its resolution of January 7, 1910, aforesaid. Said Board did by resolution of the same date approve and adopt the report, map, plan and profile of the Board of Water Supply dated November 15, 1909, and declared the same to be the final map, plan or plans approved and adopted by the Board of Estimate and Apportionment pursuant to the provisions of Chapter 724 of the Laws of 1905 as amended.

The petition in substance prays for the approval by this Commission of the plan of the Board of Water Supply of The City of New York, duly submitted to and approved and adopted by the Board of Estimate and Apportionment of The City of New York, for the distribution of the water supply to be secured from the Catskill Mountain sources to the various boroughs of The City of New York. The general plan for the additional water supply for New York City, approved by this Commission on the fourteenth day of May, 1906, provided for the construction of storage reservoirs in the Catskill Mountains and an aqueduct running from such reservoirs to New York City. It was brought out at that time that the plans for distribution of the water to the various boroughs were only tentative and that the same would be covered by a subsequent application to this Commission. The present petition, therefore, relates only to an extension or modification of the original plan for distributing water to various boroughs of New York City. The proposed plan specifically contemplates the distribution by means of a deep pressure tunnel from Hill View Reservoir through the Boroughs of The Bronx and Manhattan and extending to Brooklyn, supplemented by pipe lines to the Boroughs of Queens and Richmond, of the entire supply of water that may be obtained from the Catskill sources. In the Borough of Richmond it is proposed to construct a reservoir of four hundred or five hundred million gallons capacity for local distribution purposes.

The evidence shows that exhaustive studies have been conducted by the engineers for the City to determine the most feasible and suitable method for the distribution of this Catskill Mountain supply to the various City boroughs. The reports and data submitted to this Commission by the Board of Water

Supply with the petition, together with the evidence given at the hearing, indicate clearly that the plan proposed, namely, the pressure tunnel project, is both feasible and economical. The information at hand and the evidence adduced at the hearings also clearly indicate that the proposed plan is thoroughly adequate to meet all reasonable needs of The City for a considerable period of time and will result in the least possible inconvenience to the public and do the least damage to property during its construction.

It is also shown that the increased pressure which will be available from the proposed tunnel in some of the districts to be served will result in a great saving to the City by obviating the necessity of pumping large amounts of water, which, under any plan contemplating small pipes, would have to be pumped in order to afford sufficient pressure for satisfactory domestic service and fire protection.

The Commission has made a careful study of the project proposed, and of the evidence submitted by the petitioner, and is of the opinion that the proposed plans are both wise and economical.

It is evident that some proper method for the distribution of the proposed Catskill Mountain water supply to the various boroughs of New York City is absolutely essential to the successful completion and operation of that proposed system, and it having been clearly shown that the proposed plan is both feasible and economical, this Commission, therefore, finds:

That the plans of the petitioner are justified by public necessity.

The present petition does not contemplate any action on the part of The City of New York that will affect in any manner whatever any other municipality or civil division of the state or the inhabitants thereof, particular consideration being given to their present and future necessities for sources of water supply.

The plan of the City to pay for any and all damages that may result from the execution of said plans and the acquiring of any lands that may be necessary therefor is to purchase the lands and with the money allowed it by the Board of Estimate and Apportionment to pay for such lands and for any and all damages, whether direct or indirect, that will result therefrom.

The Commission therefore finds and determines:

First—That the plans of the petitioner are justified by public necessity.

Second—That the plans of the petitioner are just and equitable to other municipalities and civil divisions of the state affected thereby, and to the inhabitants thereof, particular consideration being given to their present and future necessities for sources of water supply.

Third—That the plans of the petitioner make fair and equitable provisions for the determination and payment of any and all damages to persons and property, both direct and indirect, which may result from the execution of the plans of the petitioner or the acquisition of the lands therefor.

The State Water Supply Commission does therefore grant the petition and approve the application and plans of the petitioner.

In Witness Whereof, The State Water Supply Commission hath caused this determination and approval to be signed by the Commission and caused its official seal to be affixed hereto, and the same with all maps, plans, surveys and other documents and papers relating thereto filed in its office in the City of Albany this 20th day of October, 1910.

HENRY H. PERSONS,
President.

[L. S.]

JOHN A. SLEICHER,
MILO M. ACKER,
CHARLES DAVIS,
ROBERT H. FULLER,
Commissioners.

STATE OF NEW YORK,
CITY AND COUNTY OF ALBANY } *ss.:*

I, DAVID R. COOPER, Secretary of the State Water Supply Commission, State of New York, do hereby certify that the foregoing is a true copy of original decision in the matter of the application of The City of New York to the State Water Supply Commission for the approval of the report of the Board of Water Supply of The City of New York to the Board of Estimate and Apportionment of The City of New York, dated November 15, 1909, recommending modification of the map, plan and profile, dated October 9, 1905, approved by said Commission May 14, 1906, which modification is dated November 15, 1909, and is entitled "Board of Water Supply of The City of New York. Map and profile showing manner of delivering the water to the several Boroughs," duly filed in the office of said State Water Supply Commission on the 20th day of October, 1910, and remaining on file therein. I further certify that the said copy has been compared by me with the original thereof and that the same is a correct transcript therefrom and of the whole of said original.

Witness my hand and the seal of said State Water Supply Commission, this 28th day of October, 1910.

[L. S.] DAVID R. COOPER,
Secretary.

Canvass of Bids Opened May 16, 1911, for Contract 63, for the Con

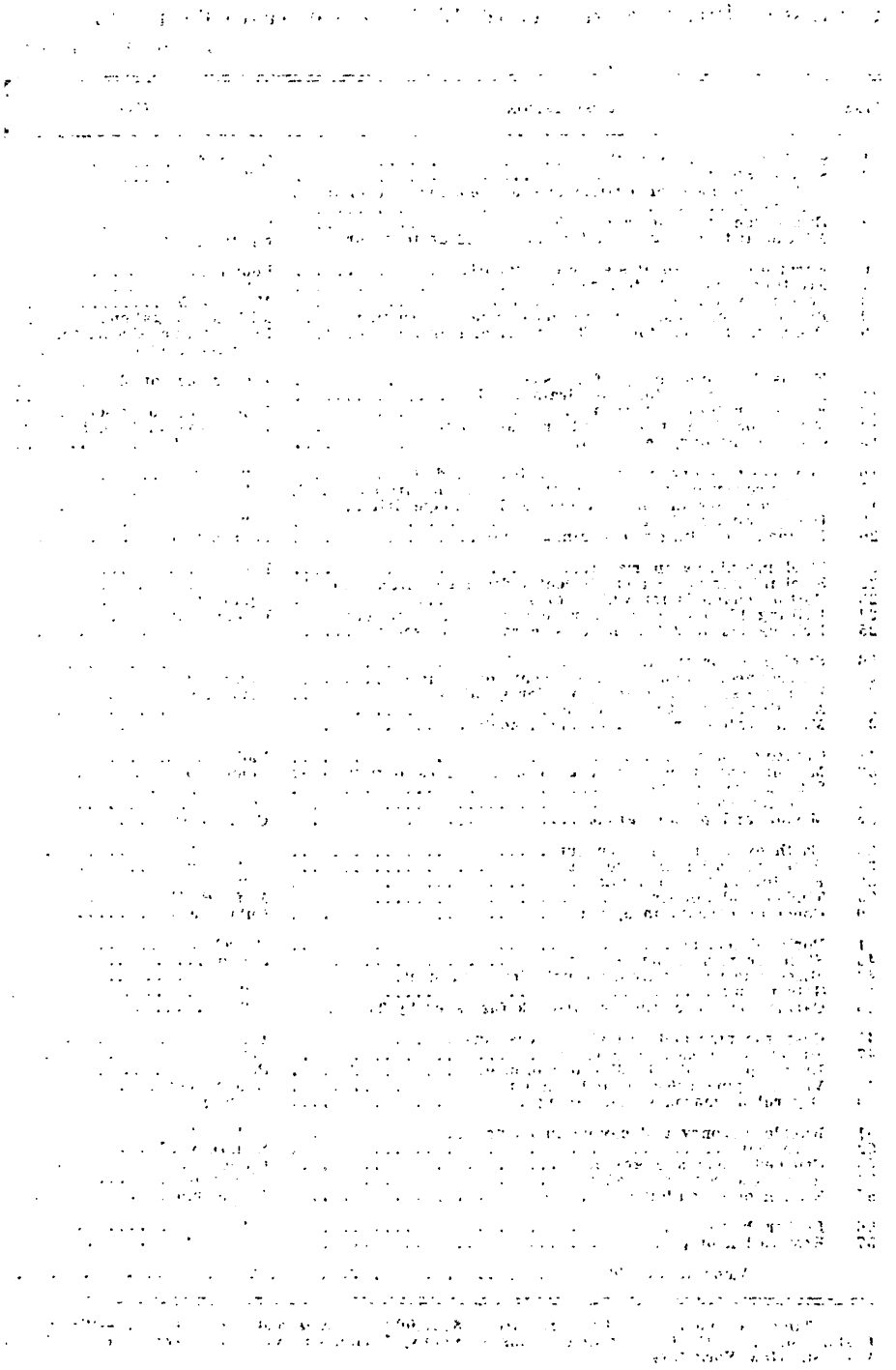
Item	Description	Unit	Quantity
1	Shaft 1	Linear foot	2
2	Sinking Shaft 5 in earth	" "	
3	Sinking upper portion of Shaft 3	" "	
4	Sinking lower portion of Shaft 3	" "	1
5	Sinking all shafts or portions of shafts not included in Items 1, 2, 3 and 4	" "	6
6	Refilling Shaft 1	Linear foot of shaft refilled	
7	Drain tunnel from Shaft 3, complete	Linear foot	
8	Excavation of main and connection tunnels	Cubic yard	234,0
9	Additional trimming in shafts and tunnels	Square yard	2,0
10	Furnishing structural steel roof support	Pound	1,350,0
11	Erecting structural steel roof support	"	1,350,0
12	Temporary timbering	M ft. B. M.	5
13	Pumping from shafts and tunnels during construction	Million foot-gallons	100,0
14	Drainage channels for shafts and tunnels	Linear foot of shafts and tunnels	22,4
15	Forms for outer lining of Shafts 2, 3, 4 and 5	Linear foot of shaft	7
16	Forms for lining of steel risers	Linear foot of riser	5
17	Forms for lining of main tunnels and Shaft 3 connection tunnel	Linear foot of tunnel	21,4
18	Concrete masonry in shafts	Cubic yard	6,0
19	Concrete masonry in main tunnel and Shaft 3 connection tunnel	" "	86,0
20	Excess concrete masonry in shafts and tunnels	" "	2,0
21	Brick masonry in shafts and tunnels	" "	2
22	Dry packing in tunnels	" "	6,5
23	Steel interlining in risers	Pound	140,0
24	Venturi meter fittings	Lump sum	.....
25	Drilling 1½-inch or smaller holes in rock or masonry	Linear foot	1,0
26	Drilling 1¾-inch to 2½-inch holes in rock or masonry	" "	2,0
27	Steel pipe for grouting, etc	" "	30,0
28	Miscellaneous plant and equipment for grouting	Lump sum	.....
29	High-pressure air-compressors for grouting	Compressor	1
30	Air-stirring grouting machines	Machine	
31	Mechanically-stirring grouting machines	Machine	
32	Grouting pads	Pad	1
33	Making connections of tank grouting machines to grout pipes	Connection	5,0
34	Setting grouting pads	Setting	1,5
35	Sand for grout	Ton	3,5
36	Mixing and placing grout	Cubic yard	5,0
37	Earth excavation in open cut	" "	9,0
38	Rock excavation in open cut	" "	4,3
39	Refilling and embanking	" "	9,6
40	Timber and lumber	M ft. B. M.	1
41	Concrete masonry in open cut	Cubic yard	1,7
42	Portland cement	Barrel	180,0
43	Steel for reinforcing concrete	Pound	70,0
44	Miscellaneous cast iron, wrought iron and steel	"	120,0
45	Galvanizing	"	30,0
46	Caring for and setting metal-work furnished by The City	"	440,0
47	Cast-iron pipe and special pipe castings	Ton	1
48	Bronze pipe and miscellaneous bronze	Pound	1,0
49	Vitrified pipe, 15-inch and smaller	Linear foot	2,5
50	Dry rubble masonry and paving	Cubic yard	1
51	Rubble masonry and paving in mortar	" "	1
52	Crushed stone and gravel	" "	3
53	Section office buildings	Lump sum	....
54	Locker houses	Lump sum	....
	Amounts of bids		

Time: 40 months Bond required: $800,000 *Awarded contract A—Mason & P
struction Company, 704-709 Pennsylvania Building, Philadelphia, Pa. D—Pittsburg Contractin
Incorporated, 507 Fifth Ave., New York City G—Bradley Contracting Company, 1 Madison A
York City

STRUCTION OF A POR
BOROUGH OF

*A	B
$335.00	$300.0
292.00	250.0
330.00	250.0
310.00	250.0
310.00	300.0
10.00	15.0
45.00	187.
8.30	8.
5.00	5.
.03	.
.01	.
60.00	65.0
.30	.
1.25	1.
10.00	8.0
4.50	4.0
4.00	4.0
9.50	9.
6.75	6.
3.00	3.
16.00	20.
2.50	2.
.10	.
16,000.00	15,000.
.40	.
.60	.
.20	.
4,000.00	5,000.
300.00	300.
300.00	300.
600.00	300.
75.00	80.
1.00	1.
1.50	1.
3.25	1.
5.00	8.
3.00	1.
4.00	1.
.50	.
65.00	55.
10.00	6.
1.50	1.
.05	.
.07	.
.04	.
.02	.
100.00	95.
.65	.
1.25	.
4.00	3.
5.00	5.
2.25	2.
5,000.00	3,600.
6,000.00	3,750.
$3,709,372.00	$3,775,552.

r Company, Richmond, H
pany, Forbes and Jumon
New York City H—M



Canvass of Bids Opened May 16, 1911, for Contract 65, for the Con
Boroughs of Th

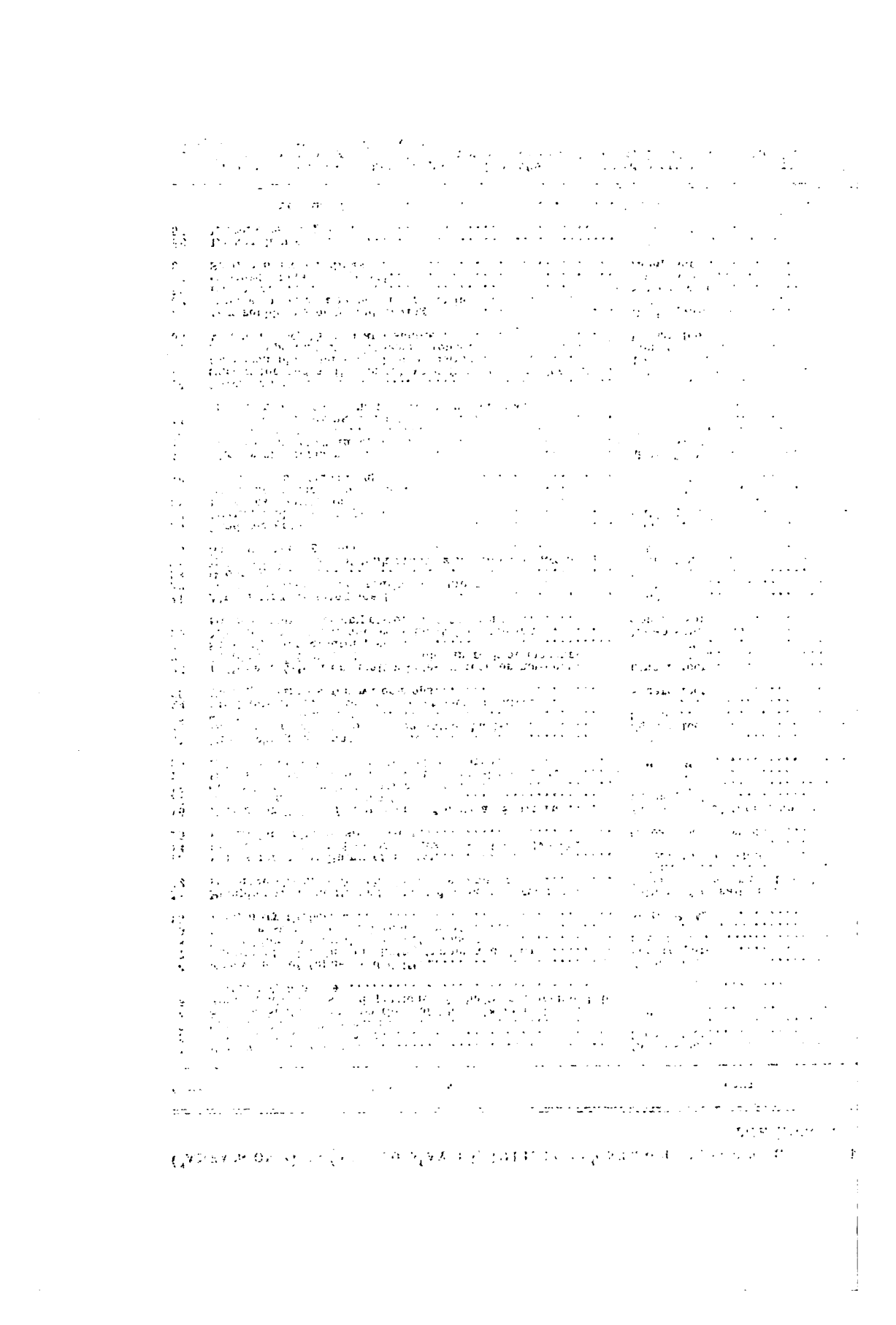
Item	Description	Unit
1	Sinking Shaft 7 in earth	Linear foot
2	Sinking Shaft 11	" "
3	Sinking all shafts or portions of shafts not included in Items 1 and 2	" "
4	Excavation of tunnel and drift	Cubic yard
5	Additional trimming in shafts, tunnel and drainage drift	Square yard
6	Furnishing structural steel roof support	Pound
7	Erecting structural steel roof support	"
8	Temporary timbering	M ft. B. M.
9	Pumping from shafts and tunnel during construction	Million foot-gallons
10	Drainage channels for shafts, tunnel and drainage drift	Linear foot of shafts, tunnel drainage drift
11	Forms for outer lining of all shafts	Linear foot of shaft
12	Forms for inner lining of drainage shaft	" " " "
13	Forms for lining of risers	Linear foot of riser
14	Forms for lining tunnel and drainage drift	Linear foot of tunnel and dri
15	Concrete masonry in shafts	Cubic yard
16	Concrete masonry in tunnel and drainage drift	" "
17	Excess concrete masonry in shafts, tunnel and drainage drift	" "
18	Brick masonry in shafts, tunnel and drainage drift	" "
19	Dry packing in tunnel	" "
20	Drainage interlining in drainage shaft	Square foot
21	Steel interlining in risers	Pound
22	Steel interlining in and adjacent to drainage drift at Shaft 11	"
23	Cutting channels for water stops	Square foot
24	Drilling 1½-inch or smaller holes in rock or masonry	Linear foot
25	Drilling 1¾ to 2½-inch holes in rock or masonry	" "
26	Steel pipe for grouting, etc	" "
27	Miscellaneous plant and equipment for grouting	Lump sum
28	High-pressure air-compressors for grouting	Compressor
29	Air-stirring grouting machines	Machine
30	Mechanically-stirring grouting machines	"
31	Grouting pads	Pad
32	Making connections of tank grouting machines to grout pipes	Connection
33	Setting grouting pads	Setting
34	Sand for grout	Ton
35	Mixing and placing grout	Cubic yard
36	Earth excavation in open cut	" "
37	Rock excavation in open cut	" "
38	Refilling and embanking	" "
39	Timber and lumber	M ft. B. M.
40	Concrete masonry in open cut	Cubic yard
41	Portland cement	Barrel
42	Steel for reinforcing concrete	Pound
43	Miscellaneous cast iron, wrought iron and steel	"
44	Galvanizing	"
45	Caring for and setting metal-work furnished by The City	"
46	Cast-iron pipe and special pipe castings	Ton
47	Miscellaneous gates and valves	Gate
48	Bronze pipe and miscellaneous bronze	Pound
49	Vitrified pipe (20-inch and smaller)	Linear foot
50	Dry rubble masonry and paving	Cubic yard
51	Rubble masonry and paving in mortar	" "
52	Pavement	Square yard
53	Crushed stone and gravel	Cubic yard
54	Reinforced concrete ladders	Linear foot
55	Section office buildings	Lump sum
56	Locker houses	" "
57	Restoration of parks	" "
	Amounts of bids	

Time: 42 months Bond required: $900,000 *Awarded contract A—Pittsbur
Boston, Mass. C—Bradley Contracting Company, 1 Madison Ave., New York City D—
Wall St., New York City

CTION OF A PORTION OF THE CITY TUNNEL OF THE CATSI
ONX AND MANHATTAN

UANTITY	*A	B	C	D	
20	$400.00	$225.00	$421.87	$400.00	
435	400.00	225.00	421.87	440.00	
2,090	400.00	255.00	421.87	440.00	
310,000	7.75	9.90	11.00	10.00	
1,500	3.00	4.50	6.00	14.00	
400,000	.03	.03½	.03	.04	
400,000	.00½	.01	.01	.03	
500	50.00	60.00	75.00	100.00	
250,000	.20	.30	.50	.30	
30,950	1.50	1.40	1.30	2.00	
2,350	10.00	7.00	10.00	10.00	
425	10.00	8.00	10.00	10.00	
850	10.00	4.00	10.00	10.00	
28,450	10.00	2.25	4.00	4.00	
18,600	8.00	8.00	10.00	12.00	
120,000	3.00	3.00	3.00	3.00	
2,000	3.00	3.00	3.00	3.00	
300	15.00	18.00	25.00	15.00	
9,000	3.00	3.00	4.00	2.50	
20,500	.30	.35	1.00	.30	
200,000	.05	.06	.06	.10	
60,000	.06	.06	.06	.10	
450	1.00	2.00	6.00	3.00	
1,000	.25	.45	.50	.30	
3,000	.50	.60	.50	.40	
40,000	.20	.30	.25	.30	
....	5,000.00	4,500.00	5,000.00	10,000.00	
14	200.00	350.00	500.00	250.00	
7	250.00	300.00	500.00	350.00	
7	400.00	300.00	500.00	500.00	
50	12.00	60.00	100.00	100.00	
8,000	.50	1.00	1.00	3.00	
2,500	1.00	1.25	1.00	6.00	
4,000	2.00	2.00	2.25	3.00	
6,000	1.00	5.00	5.00	9.00	
7,200	2.00	2.50	5.00	4.00	
3,300	4.00	5.00	7.00	5.00	
5,500	1.00	.75	.50	4.00	
150	55.00	60.00	75.00	75.00	
2,700	6.50	8.50	10.00	15.00	
250,000	1.35	1.45	1.60	2.00	
160,000	.04	.04	.04	.06	
115,000	.06	.08	.05	.10	
30,000	.05	.05	.02	.03	
500,000	.02	.02½	.03	.07	
80	100.00	80.00	100.00	100.00	
12	75.00	100.00	150.00	1,000.00	
8,000	.50	.75	1.00	1.00	
2,000	1.00	1.50	2.50	1.50	
100	3.00	4.00	6.00	6.00	
100	3.00	5.00	9.00	6.50	
2,000	3.00	2.50	4.50	4.00	
300	2.00	2.00	2.00	3.00	
25	2.00	4.00	15.00	12.00	
....	9,000.00	12,000.00	10,500.00	12,000.00	
....	8,000.00	10,000.00	10,000.00	10,000.00	
....	9,000.00	2,000.00	4,950.00	5,000.00	
.....	$5,580,225.00	$5,775,392.50	$6,798,819.15	$6,822,100.00	$6,8

cting Company, Forbes and Jumonville Sts., Pittsburg, Pa. B—Patr
A. Gillespie Company, 50 Church St., New York City E—The Degn



Canvass of Bids Opened May 16, 1911, for Contract 66, for the Constr the Borough

Item	Description	Unit
1	Removing buildings	Lump sum
2	Sinking Shaft 17 in earth	Linear foot
3	Sinking Shaft 18 in earth	" "
4	Sinking Shaft 13 and portions of Shaft 18 in rock	" "
5	Sinking all shafts and portions of shafts not included in Items 2, 3 and 4	" "
6	Excavation of tunnel and drift	Cubic yard
7	Additional trimming in shafts, tunnel and drift	Square yard
8	Furnishing structural steel roof support	Pound
9	Erecting structural steel roof support	"
10	Temporary timbering	M ft. B. M.
11	Pumping from shafts and tunnel during construction	Million foot-gallons
12	Drainage channels for shafts, tunnel and drift	Linear foot of shaft, tunnel and drift
13	Forms for outer lining of shafts	Linear foot of shaft
14	Forms for outer and inner linings of section valve shafts	" " " "
15	Forms for lining of steel risers	Linear foot of riser
16	Forms for lining of tunnel and of drift at Shaft 16	Linear foot of tunnel and drift
17	Concrete masonry in shafts	Cubic yard
18	Concrete masonry in tunnel and drift	" "
19	Excess concrete masonry in shafts, tunnel and drift	" "
20	Brick masonry in shafts, tunnel and drift	" "
21	Dry packing in tunnel and drift	" "
22	Drainage interlining in section valve shafts	Square foot
23	Steel interlining in risers	Pound
24	Steel interlining in tunnel and at section valves	"
25	Cutting channels for water-stops	Square foot
26	Drilling 1½-inch or smaller holes in rock or masonry	Linear foot
27	Drilling 1¾-inch to 2½-inch holes in rock or masonry	" "
28	Steel pipe for grouting, etc	" "
29	Miscellaneous plant and equipment for grouting	Lump sum
30	High-pressure air-compressors for grouting	Compressor
31	Air-stirring grouting machines	Machine
32	Mechanically-stirring grouting machines	"
33	Grouting pads	Pad
34	Making connections of tank grouting machines to grout pipes	Connection
35	Setting grouting pads	Setting
36	Sand for grout	Ton
37	Mixing and placing grout	Cubic yard
38	Earth excavation in open cut	" "
39	Rock excavation in open cut	" "
40	Refilling and embanking	" "
41	Timber and lumber	M ft. B. M.
42	Concrete masonry in open cut	Cubic yard
43	Portland cement	Barrel
44	Steel for reinforcing concrete	Pound
45	Miscellaneous cast iron, wrought iron and steel	"
46	Galvanizing	"
47	Caring for and setting metal-work furnished by The City	"
48	Cast-iron pipe and special pipe castings	Ton
49	Bronze pipe and miscellaneous bronze	Pound
50	Vitrified pipe, 18-inch and smaller	Linear foot
51	Dry rubble masonry and paving	Cubic yard
52	Rubble masonry and paving in mortar	" "
53	Pavement	Square yard
54	Crushed stone and gravel	Cubic yard
55	Section office buildings	Lump sum
56	Locker houses	" "
57	Restoration of parks	" "
	Amounts of bids	

Time: 52 months Bond required: $900,000 *Awarded contract A—Grant Smith 42nd St., New York City C—The Degnon Contracting Company, 60 Wall St., New York City pany, 50 Church St., New York City

OTION OF A PORTION OF THE CITY TUNNEL OF THE CATSKILL AQUEDUCT IN F MANHATTAN

UANTITY	*A	B	C	D	E	AVERAGE	ITEM
....	$1,000.00	$1,000.00	$15,000.00	$10,000.00	$5,000.00	$6,400.00	1
20	275.00	350.00	375.00	503.85	400.00	380.77	2
28	275.00	350.00	375.00	503.85	400.00	380.77	3
405	330.00	400.00	360.00	503.85	500.00	418.77	4
815	330.00	400.00	360.00	503.85	490.00	416.77	5
318,000	11.25	9.75	11.50	12.00	12.60	11.42	6
1,100	5.00	3.00	3.00	6.00	14.00	6.20	7
380,000	.03	.03	.03	.03	.04	.03	8
380,000	.01½	.01	.01½	.01	.03	.01½	9
325	70.00	50.00	60.00	75.00	100.00	71.00	10
100,000	.25	.25	.50	.50	.30	.36	11
24,465	2.00	3.00	4.00	1.30	2.00	3.46	12
740	3.00	10.00	4.00	10.00	10.00	3.40	13
340	12.00	7.00	5.00	20.00	10.00	10.80	14
1,525	5.00	2.00	1.00	10.00	10.00	5.60	15
23,250	4.00	10.00	4.00	4.00	4.00	5.20	16
9,100	10.00	9.00	10.00	10.00	12.00	10.20	17
85,000	7.50	10.50	10.50	8.00	10.00	9.30	18
2,000	3.00	3.00	3.00	3.00	3.00	3.00	19
200	25.00	15.00	16.00	25.00	15.00	19.20	20
6,100	3.50	1.50	3.00	4.00	2.50	2.90	21
13,500	1.25	.25	.30	1.00	.30	.62	22
65,000	.03	.03	.03	.06	.10	.03	23
55,000	.03	.10	.03	.06	.10	.03½	24
1,500	2.00	1.50	3.00	6.00	3.00	3.10	25
1,000	.40	.40	.25	.50	.30	.37	26
3,000	.50	.50	.30	.50	.40	.44	27
30,000	.30	.26	.20	.25	.30	.26	28
....	5,000.00	6,000.00	5,000.00	5,000.00	9,000.00	6,000.00	29
12	300.00	250.00	250.00	500.00	250.00	310.00	30
6	300.00	350.00	250.00	500.00	350.00	350.00	31
6	300.00	500.00	200.00	500.00	500.00	400.00	32
40	80.00	60.00	50.00	100.00	100.00	78.00	33
5,000	1.75	2.00	.60	1.00	3.00	1.67	34
2,000	1.00	1.00	1.50	1.00	6.00	2.10	35
3,500	1.75	2.50	1.50	2.25	3.00	2.20	36
6,000	10.00	2.00	4.00	5.00	9.00	6.00	37
12,500	2.00	3.00	2.40	5.00	4.00	3.28	38
5,000	4.00	6.00	4.50	7.00	5.00	5.30	39
12,000	1.00	1.00	.60	.50	4.00	1.42	40
250	60.00	50.00	40.00	75.00	75.00	60.00	41
2,000	8.00	7.00	10.00	10.00	15.00	10.00	42
35,000	1.40	1.36	1.80	1.60	2.00	1.63	43
00,000	.05	.04	.05	.03	.06	.04½	44
35,000	.07	.06	.07	.05	.10	.07	45
35,000	.05	.04	.02	.02	.03	.03	46
00,000	.03	.02½	.06	.03	.07	.04	47
60	100.00	100.00	60.00	100.00	100.00	92.00	48
600	1.00	1.00	.75	1.00	1.00	.95	49
4,000	1.00	.50	1.25	2.25	1.25	1.25	50
50	5.00	3.00	4.00	6.00	6.00	4.80	51
150	7.00	5.00	5.00	9.00	6.50	6.50	52
5,000	5.00	4.00	4.00	4.50	4.00	4.30	53
400	2.50	2.50	2.00	2.00	3.00	2.40	54
....	5,000.00	3,400.00	4,000.00	7,000.00	8,000.00	5,480.00	55
....	8,000.00	10,500.00	6,000.00	7,500.00	7,500.00	7,900.00	56
....	10,000.00	10,000.00	10,000.00	5,850.00	5,000.00	8,170.00	57
.....	$4,512,605.00	$4,719,925.00	$4,961,645.00	$5,028,686.20	$5,550,005.00		

., and Locher, Rome, N. Y. B—The United Engineering and Contracting Company, 17 West —Bradley Contracting Company, 1 Madison Ave., New York City E—The T. A. Gillespie Com-

Canvass of Bids Opened May 16, 1911, for Contract 67, for the C

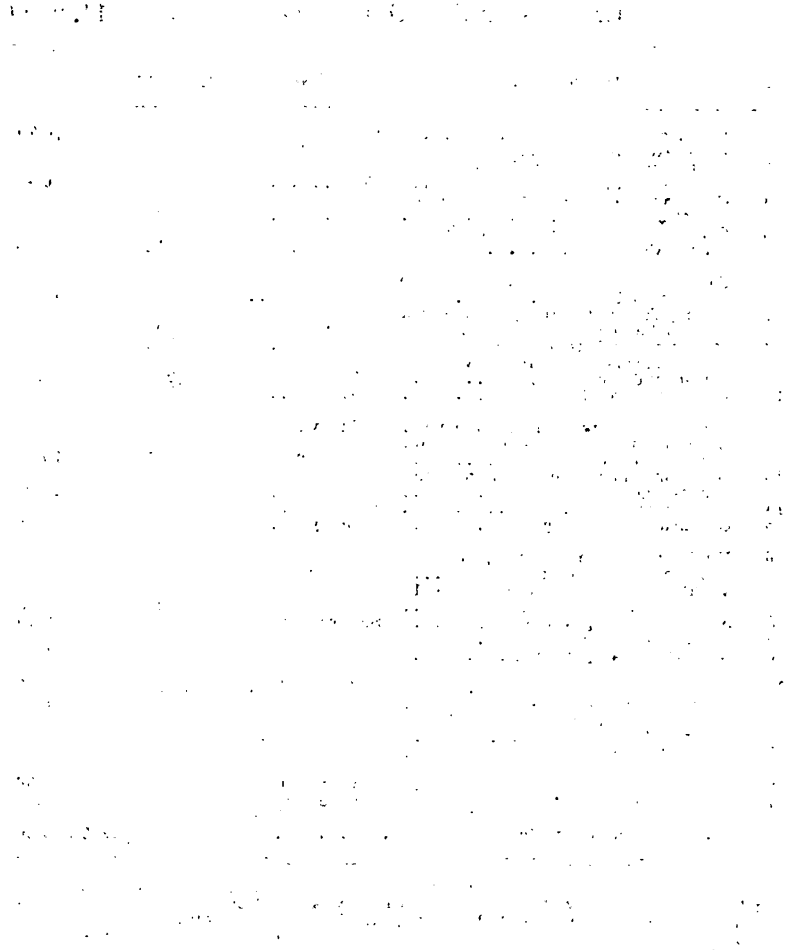
Item	Description	Unit
1	Removing buildings	Lump sum
2	Excavation of Shaft 19 in earth	Linear foot
3	Excavation of Shaft 20 in earth	" "
4	Excavation of Shaft 21 in earth	" "
5	Excavation of Shaft 22 in earth	" "
6	Excavation of Shaft 23 in earth	" "
7	Excavation of Shaft 24 in earth	" "
8	Excavation of Shafts 19, 20 and 22 in rock	" "
9	Excavation of Shaft 21 in rock	" "
10	Excavation of upper portions of Shafts 23 and 24 in rock	" "
11	Excavation of lower portions of Shafts 23 and 24 in rock	" "
12	Excavation of tunnels and drifts	Cubic yard
13	Additional trimming in shafts, tunnels and drifts	Square yard
14	Furnishing structural steel roof support	Pound
15	Erecting structural steel roof support	"
16	Temporary timbering	M ft. B. M.
17	Pumping from shafts and tunnels during construction	Million foot-gallons
18	Drainage channels for shafts, tunnels and drifts	Linear foot of shafts, tu and drifts
19	Forms for outer lining of all shafts	Linear foot of shaft
20	Forms for inner lining of drainage shaft	" "
21	Forms for lining risers	Linear foot of riser
22	Forms for lining tunnels and drifts	Linear foot of tunnel and d
23	Concrete masonry in shafts	Cubic yard
24	Concrete masonry in tunnels and drifts	" "
25	Excess concrete masonry in shafts, tunnels and drifts	" "
26	Brick masonry in shafts, tunnels and drifts	" "
27	Dry packing in tunnels and drift	" "
28	Drainage interlining in drainage shaft	Square foot
29	Steel interlining in risers	Pound
30	Steel interlining in and adjacent to drainage drift	"
31	Cutting channels for water stops	Square foot
32	Drilling 1½-inch or smaller holes in rock or masonry	Linear foot
33	Drilling 1¾-inch to 2½-inch holes in rock or masonry	" "
34	Steel pipe for grouting, etc	" "
35	Miscellaneous plant and equipment for grouting	Lump sum
36	High-pressure air-compressors for grouting	Compressor
37	Air-stirring grouting machines	Machine
38	Mechanically-stirring grouting machines	"
39	Grouting pads	Pad
40	Making connections of tank grouting machines to grout pipes	Connection
41	Setting grouting pads	Setting
42	Sand for grout	Ton
43	Mixing and placing grout	Cubic yard
44	Excavation in open cut	" "
45	Refilling and embanking	" "
46	Timber and lumber	M ft. B. M.
47	Concrete masonry in open cut	Cubic yard
48	Portland cement	Barrel
49	Steel for reinforcing concrete	Pound
50	Miscellaneous cast iron, wrought iron and steel	"
51	Galvanizing	"
52	Caring for and setting metal-work furnished by The City	"
53	Cast-iron pipe and special pipe castings	Ton
54	Bronze pipe and miscellaneous bronze	Pound
55	Vitrified pipe, 18-inch to 24-inch, inclusive	Linear foot
56	Vitrified pipe, 15-inch and smaller	" "
57	Dry rubble masonry and paving	Cubic yard
58	Rubble masonry and paving in mortar	" "
59	Pavement	Square yard
60	Crushed stone and gravel	Cubic yard
61	Reinforced concrete ladders	Linear foot
62	Section and locker houses	Lump sum
63	Sinking casing and core drilling	Linear foot
64	Casing left in place	Pound
	Amounts of bids	

Time: 54 months Bond required: $700,000 * Awarded contract A—Holbroo City B—The United Engineering and Contracting Company, 17 West 42nd St., New Yo E—The T. A. Gillespie Company, 50 Church St., New York City F—The Degnon Contra Company, 11 Pine St., New York City

RUCTION OF A PORTION OF THE C
BROOKLYN

QUANTITY	*A	B
.....	$5,000.00	$1.00
42	466.00	350.00
95	471.00	450.00
35	1,082.00	1,000.00
93	456.00	440.00
120	735.00	750.00
100	614.00	650.00
1,510	354.00	350.00
705	426.00	400.00
215	423.00	350.00
150	393.00	360.00
157,000	10.70	10.20
1,500	4.00	3.00
1,600,000	.04	.04
1,600,000	.02½	.01
290	70.00	50.00
500,000	.35	.40
24,350	2.50	8.00
2,900	7.50	10.00
730	8.75	4.00
2,350	2.00	2.00
21,320	3.75	10.00
26,000	10.85	9.00
70,000	10.25	11.00
2,000	3.00	3.00
200	20.00	15.00
6,500	2.50	2.00
36,500	.25	.25
820,000	.07	.08
70,000	.08	.10
475	2.50	1.50
1,000	1.00	.40
3,000	2.50	.50
40,000	.50	.25
.....	5,000.00	5,000.00
10	300.00	250.00
5	300.00	350.00
5	350.00	500.00
40	100.00	60.00
8,000	1.50	2.00
2,500	1.50	1.00
4,000	2.00	2.25
6,000	6.00	4.00
11,500	3.50	3.00
4,800	1.00	1.00
250	75.00	50.00
3,200	12.00	7.00
205,000	1.50	1.34
1,000,000	.04½	.04
450,000	.07	.06
45,000	.06	.04
930,000	.06	.02½
100	80.00	100.00
5,000	.80	1.00
500	2.50	.60
1,200	1.25	.45
100	5.00	3.00
100	6.00	5.00
5,500	3.00	3.00
500	3.00	2.50
50	2.00	5.00
.....	8,000.00	20,000.00
8,000	5.00	5.00
5,000	.06	.10
	$5,272,435.00	$5,295,218.50

t and Rollins Corporation, 103 Park Ave
C—J. F. Cogan Company, Contractor
mpany, 60 Wall St., New York City



Canvass of Bids Opened October 31, 1911, for Contract 7

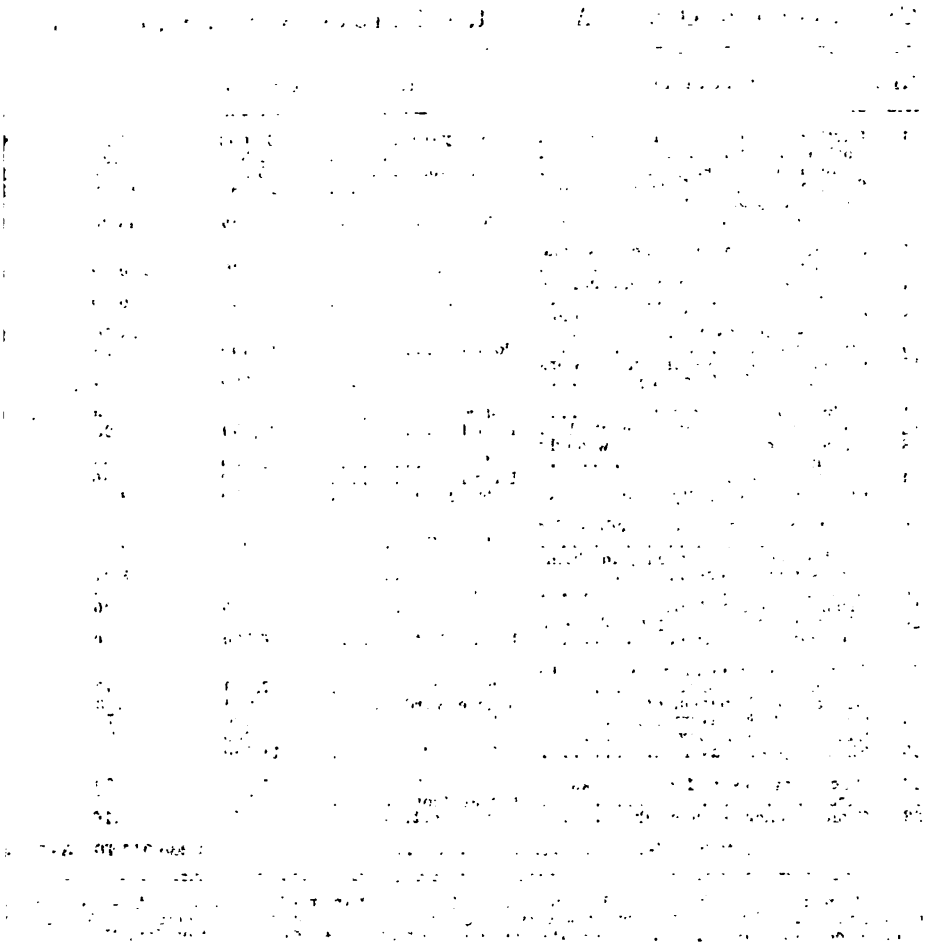
Item	Description	Unit	Quantity	*A	B
1	Earth excavation and refilling.....	Cubic yard...	37,000	$0.70	$0.82
2	Rock excavation	" " ...	200	4.00	2.00
3	Cast-iron pipe, straight hub-and-spigot	Ton	6,800	26.40	27.48
4	Cast-iron hub-and-spigot special castings	"	220	55.00	54.00
5	Cast-iron flanged pipe and flanged specials	"	12	60.00	65.00
6	Cast-iron valve-boxes, manhole heads and covers.....	"	24	50.00	45.00
7	Caring for and setting metal-work furnished by The City.....	Pound	240,000	.01½	.01
8	Structural and reinforcing steel...	"	25,000	.04	.04
9	Miscellaneous cast iron, wrought iron and steel.....	"	4,000	.07	.04
10	Portland cement	Barrel	550	1.65	1.50
11	Concrete masonry under pavement.	Cubic yard...	40	10.00	7.00
12	Concrete masonry as cradles for sewers or drains.....	" " ...	50	10.00	4.00
13	Brick or concrete masonry in chambers and sewers.....	" " ...	280	12.00	8.00
14	Lead pipe	Pound	500	.15	.20
15	Crushed stone and gravel.....	Cubic yard...	4	3.00	.01
16	Vitrified or cement pipe, 3 to 8 inches in diameter.....	Linear foot...	150	.50	1.50
17	Vitrified or cement pipe, 9 to 15 inches in diameter.....	" " ...	800	1.00	1.00
18	Asphalt block pavement.....	Square yard..	90	2.00	2.00
19	Belgian block pavement.....	" " ..	5,000	.35	.30
20	Granite block pavement.....	" " ..	100	1.00	.30
21	Macadam pavement	" " ..	4,500	.70	.30
22	Sheet asphalt pavement.....	" " ..	200	1.50	3.90
23	Flag sidewalks and cross-walks...	" " ..	400	.20	.30
24	Brick gutter	" " ..	20	.20	1.00
25	Cobblestone gutter	" " ..	550	.30	.30
26	Curb	Linear foot...	100	.06½	.30
27	Cement concrete sidewalk.....	Square foot...	100	.15	.15
	Amounts of bids.....			$237,000.00	$243,764.04

Time: 12 months Bond required: At least one-third of contract amount *Award and Thomas P. Murphy, 25th Ave. and Cropsey Ave., Brooklyn, N. Y. C—Joseph Burns, 1 Ocean Parkway and Avenue O, Brooklyn, N. Y. F—Cranford Company, 52 Ninth St., Brook I—Rodgers & Hagerty, Incorporated, 41 Park Row, New York City J—Borough Developme

FOR THE CONSTRUCTION OF T

C	D	E
$0.95	$1.27	$0.75
2.00	3.00	1.15
26.40	25.18	30.35
70.00	67.53	65.00
70.00	56.42	65.00
50.00	56.42	63.00
.02	.02	.00⅛
.04	.05	.06
.04	.07½	.11
1.70	1.73	1.40
4.00	6.25	3.00
4.00	10.00	4.50
8.00	12.00	9.20
.12	.20	.11½
1.00	3.00	3.25
.25	.75	1.15
1.00	1.00	1.15
1.50	2.20	3.30
.40	.50	.30
.50	1.00	.45
.40	.83	.30
2.00	2.00	2.60
.25	.60	.23
.30	2.50	2.30
.30	.40	.25
.20	.75	.50
.20	.30	.20
7,602.50	$255,685.72	$262,603.50

ntract A—F. V. Smith & Son, In
st 125th St., New York City D—
N. Y. G—The Degnon Contracting
mpany, 186 Remsen St., Brooklyn, N



Canvass of Bids Opened August 1, 1911, for Contract 87, for the

Item	Description	Unit	Quantity	*A	
1	Earth excavation and refilling.....	Cubic yard.....	63,000	$1.26	
2	Rock excavation	" "	2,800	2.00	
3	66-inch steel pipe, ½-inch plate...	Linear foot.....	5,840	12.42	
4	66-inch steel pipe, 7/16-inch plate.	" "	11,180	11.38	
5	Cast-iron pipe, straight hub-and-spigot	Ton	44	45.00	
6	Cast-iron hub-and-spigot special castings	"	25	150.00	
7	Cast-iron flanged pipe and flanged specials	"	20	100.00	
8	Cast-iron valve boxes, manhole heads and covers.....	"	50	75.00	
9	Steel castings	Pound	12,000	.15	
10	Caring for and setting metal-work furnished by The City.....	"	250,000	.04½	
11	66-inch Venturi meter.....	Meter	1	2,800.00	
12	Structural and reinforcing steel...	Pound	20,000	.05	
13	Miscellaneous cast iron, wrought iron and steel.....	"	12,000	.05	
14	Portland cement	Barrel	4,200	1.50	
15	Concrete masonry under pavement.	Cubic yard.....	2,200	4.00	
16	Concrete masonry as cradles for sewers or drains.....	" "	550	4.92	
17	Brick or concrete masonry in chambers and sewers.....	" "	650	8.21	
18	Lead pipe	Pound	9,000	.26	
19	Crushed stone and gravel.....	Cubic yard.....	10	2.00	
20	Vitrified or cement pipe 3 to 8 inches in diameter.....	Linear foot.....	6,500	.30	
21	Vitrified or cement pipe 9 to 15 inches in diameter.....	" "	7,400	.50	
22	Belgian block pavement.....	Square yard.....	400	.33	
23	Granite block pavement.....	" "	200	.77	
24	Sandstone block pavement.....	" "	200	.90	
25	Sheet asphalt pavement.....	" "	11,500	1.50	
26	Flag sidewalks and cross-walks...	" "	1,100	.90	
27	Curb	Linear foot.....	550	.30	
28	Cement concrete sidewalks.....	Square foot.....	25,000	.10	
	Amounts of bids.....			$366,014.70	$439

Time: 11 months Bond required: $200,000 *Awarded contract A—William Contractors, 280 Broadway, New York City C—The Degnon Contracting Company, 60 Wall 1942 Forbes St., Pittsburg, Pa. F—Donlon Contracting Co., 84 Broadway, Brooklyn, N. Y.

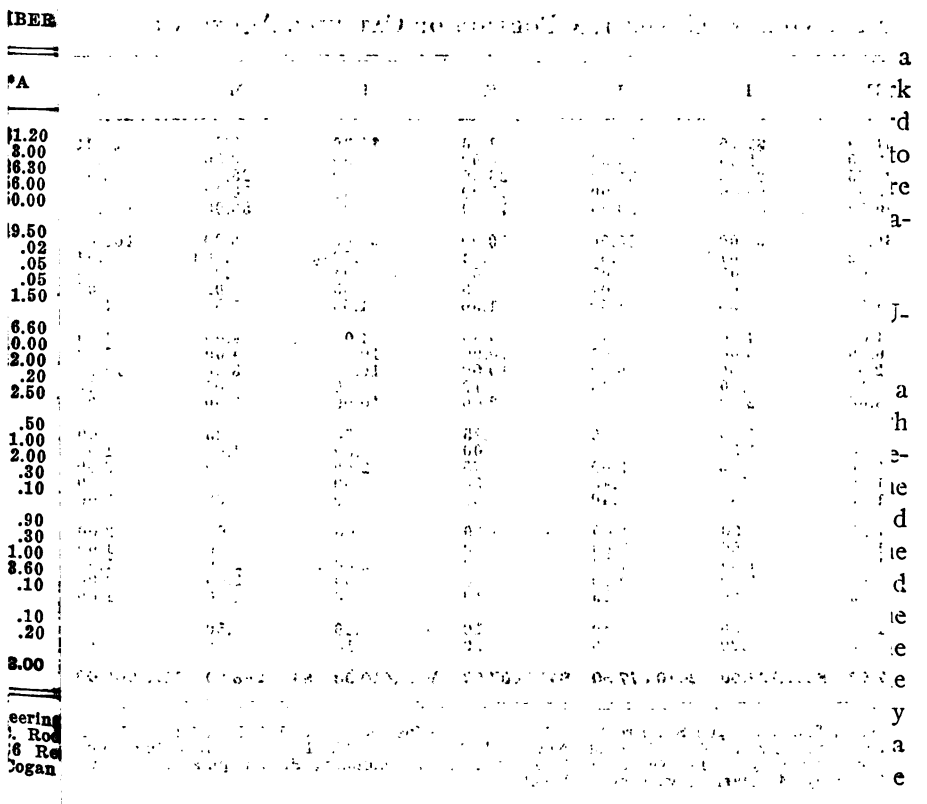
C	D	E	F	G	H	AVERAGE	ITEM
$1.60	$1.60	$1.50	$1.50	$2.25	$2.71	$1.80	1
3.00	4.00	4.00	.01	7.00	4.00	3.75	2
16.00	18.00	16.50	19.75	14.75	19.00	16.18	3
15.00	17.00	16.50	19.75	14.25	18.00	15.36	4
32.50	30.00	90.00	70.00	150.00	40.00	62.19	5
75.00	70.00	125.00	70.00	200.00	100.00	110.00	6
80.00	70.00	150.00	70.00	225.00	75.00	112.50	7
70.00	60.00	80.00	55.00	150.00	55.00	79.37½	8
.09	.04	.11	.07	.10	.12½	.10	9
.01¼	.01	.05	.02	.04	.03½	.03	10
2,500.00	2,500.00	2,500.00	4,000.00	2,000.00	3,000.00	2,787.50	11
.03½	.04	.05	.04	.05	.04	.04½	12
.05	.04	.05	.05	.05	.10	.06	13
1.50	2.00	1.50	1.70	1.60	1.50	1.60	14
4.50	4.50	6.00	5.00	6.00	4.50	4.75	15
5.00	6.00	8.00	6.50	8.00	8.00	7.05¼	16
12.00	15.00	10.00	12.00	12.00	10.00	11.15	17
.15	.10	.12	.07	.15	.25	.16¼	18
1.50	1.75	2.50	1.30	4.00	3.00	2.63	19
.15	.20	.90	.35	.30	.65	.46	20
.60	.50	1.50	1.00	.75	1.50	.92	21
1.20	.50	1.50	.40	2.00	.40	.98	22
1.20	1.00	1.75	.50	2.00	1.00	1.22½	23
1.20	.50	1.75	.40	2.00	2.00	1.34½	24
1.25	2.00	3.00	2.00	3.00	1.25	1.87½	25
1.00	1.00	.90	.25	.50	.90	.87	26
.20	.20	.50	.10	.40	.60	.41¼	27
.18	.20	.20	.20	.25	.22½	.19	28
$441,195.00	$488,267.50	$497,515.00	$519,116.00	$528,735.00	$584,515.00		

iovan and Charles Cranford, 186 Remsen St., Brooklyn, N. Y. B—J. F. Cogan Company,
ew York City D—James H. Holmes, 87 Nassau St., New York City E—Booth & Flinn, Limited,
rick McGovern, 6 Beacon St., Boston, Mass. H—Cranford Company, 52 Ninth St., Brooklyn, N. Y.

Canvass of Bids Opened S

Item	Description	Unit	Quantity
1	Earth excavation and refilling	Cubic yard	50,000
2	Rock excavation	" "	750
3	Cast-iron pipe, straight hub-and-spigot	Ton	8,900
4	Cast-iron hub-and-spigot special castings	"	300
5	Cast-iron flanged pipe and flanged specials	"	10
6	Cast-iron valve-boxes, manhole heads and covers	Ton	30
7	Caring for and setting metal-work furnished by The City	Pound	300,000
8	Structural and reinforcing steel	"	23,000
9	Miscellaneous cast iron, wrought iron and steel	"	4,500
10	Portland cement	Barrel	1,200
11	Concrete masonry in pavement foundations	Cubic yard	650
12	Concrete masonry as cradles for sewers or drains	" "	50
13	Brick or concrete masonry in chambers and sewers	" "	300
14	Lead pipe	Pound	500
15	Crushed stone and gravel	Cubic yard	10
16	Vitrified or cement pipe 3 to 8 inches in diameter	Linear foot	300
17	Vitrified or cement pipe 9 to 15 inches in diameter	" "	100
18	Asphalt block pavement	Square yard	550
19	Belgian block pavement	" "	50
20	Cobblestone pavement	" "	900
21	Granite block pavement	Square yard	5,700
22	Macadam pavement	" "	100
23	Sheet asphalt pavement	" "	3,900
24	Wood block pavement	" "	80
25	Flag sidewalks and cross-walks	" "	300
26	Curb	Linear foot	250
27	Cement concrete sidewalks	Square foot	2,000
	Amounts of bids		

Time: 12 months Bond required: $150,000 *Awarded contract A—Beav
tague St., Brooklyn, N. Y. E—Cranford Company, 52 9th St., Brooklyn, N. Y. F
Bros., 25th Ave. and Cropsey Ave., Brooklyn, N. Y. J—Borough Development Com
N. Y. N—The King, Ganey Contracting Company, 120 Broadway, New York City O



CHARLES P. BERKEY
SUB-STATION 84
NEW YORK CITY

NEW YORK, August 1, 1912.

MR. J. WALDO SMITH,
Chief Engineer, Board of Water Supply.

DEAR SIR:

In accordance with your request I hand you herewith a summary of my various reports on the geology of New York City, with reference to the pressure tunnel plan of the Board of Water Supply. This summary includes all information to date and brings together into a brief space all of the more important data obtained as the result of the extensive explorations which were made in the interest of this public work.

GEOLOGICAL FEATURES OF THE CITY DISTRIBUTION TUNNEL

An 18-mile distribution conduit is to be constructed as a pressure tunnel entirely in rock from the Yonkers line through The Bronx and Manhattan to Brooklyn. As soon as this decision was reached, preliminary studies were begun for the purpose of determining the best location of the line and related matters. It was appreciated in the beginning that many of the critical questions were essentially geological in their nature and would require special attention from that standpoint. The engineer and the geologist worked alternately on the same problems until in the opinion of both the best possible line was adopted, and the most suitable additional exploratory work was undertaken. The following pages are written as a part of the history of the development of this project from the geologic point of view.

PRELIMINARY STUDIES

Three trial lines were first laid out on a standard street map of the City from Hill View reservoir just north of the City boundary to the vicinity of Fort Greene park, Brooklyn. So far as the general topography and City development and other

engineering considerations were then known either of these three routes could have been used. Special studies, and, if need be, additional exploratory investigations, were expected to indicate which would be the most acceptable, and whether or not it might be advisable to shift even the best one to a still more favorable location. These original trial lines are shown on the accompanying map, Sheet 18.

GENERAL CONSIDERATIONS

(1) One of the essential items to be kept in view is that of length of line. Other things being equal the shorter line would be preferable.

(2) Another item is depth of tunnel. In general it would be preferable to avoid the necessity of making an excessively deep tunnel.

(3) A third is the matter of permanence. This item is judged to be closely related to the condition of the rock penetrated by the tunnel.

(4) Another is relative cost of construction, which is also in part dependent upon rock quality and rock condition, and similar factors.

QUESTIONS RAISED IN CONNECTION WITH THE DISTRIBUTION CONDUIT TRIAL LINES

(1) What rock formations must be penetrated along each of the trial lines?

(2) How much of each must be allowed for?

(3) What condition of rock is likely to be found at moderate depth?

(4) Will the rock at moderate depth be such as to permit successful and economical construction of tunnels to be used under hydraulic pressure due to Hill View reservoir?

(5) Does the character of the rock in the vicinity of the lines vary sufficiently to materially affect the cost of a tunnel if they should be shifted approximately 1,000 feet either way from their trial location?

(6) Are the suggested locations of conduit lines adapted from a geological viewpoint to the construction of pressure tunnel conduits, and, if not, what changes in these lines would be advisable?

(7) What depth must be assumed so as to avoid buried channels, excessive weakness from superficial decay, open seams, disturbed rock, and weakness due to insufficient rock cover?

(8) Are there any special sections along these trial lines where a moderate amount of exploratory work would help materially in coming to a decision on choice of line and its practicability?

(9) If so, what borings or other form of field exploratory investigation should be undertaken to determine the location and practicability of a line for the distribution tunnel?

GEOLOGICAL STUDIES

In large part these original questions depended for their correct solution on geological data. In fact, they required more detail and greater accuracy than was then available in the published reports and maps of the Greater New York area. It was necessary to determine the following points more accurately:

(a) The contacts between formations, especially where a line was drawn parallel to and near the edge of a formational boundary.

(b) Variation in the quality of rock in each formation.

(c) Any unusual structural conditions, such as fault zones or excessive jointing or interbedding.

(d) The exact location of special conditions that would in any way materially affect construction and form an essential item in the specifications and plans.

In accord with these requirements a thorough geological study was begun covering every item that seemed to have a bearing on such engineering questions. The whole immediate region was mapped in enough detail to locate all outcrops of ledges within 1,000 feet of the trial lines, as much accuracy as possible was given to the boundaries of formations, and special attention was given to all surficial evidences of unusual underground conditions. The following is a general statement of the essential features of local geology that have proved to be dependable in these studies.

Geological Formations

There are six local formations* coming within reach of these lines of sufficient permanence and individuality and areal importance to be treated as units in this study.

They are the Glacial drift, Manhattan schist, Inwood limestone, Fordham gneiss, including two large intrusive members, Yonkers gneiss and Ravenswood grano-diorite.

THE GLACIAL DRIFT

Only rarely is there any residuary soil left undisturbed by glaciation. Everywhere there is glacial drift of varying thickness through which project small portions of rock ledges as outcrops. There is almost always an abrupt break between the bed-rock and the loose drift, and the constituents of the drift differ materially from those of the rock floor. Worn boulders are common and in some cases their original sources are readily traced by the character of the rock. The bed-rock is generally smoothed and grooved in such manner as to indicate the direction of glacial movement which is about South 30° East. Therefore it is not at all unusual to find abundant boulders of Palisade trap carried from the west side of the Hudson, mixed into the drift mass. Occasional boulders are clearly identical with ledges to be found in the Highlands, or the Catskill and Helderburg regions, or still farther away.

The drift varies in thickness to more than 200 feet within the City. It is thickest in narrow valleys where, in some cases, the original contour is wholly obscured and an entirely new topography is developed on the drift. These buried valleys or other rock floor depressions usually require special exploratory investigation to determine data with sufficient accuracy for engineering uses.

There are in this district two fundamentally different types of drift as to method of deposition. They are (a) unassorted drift, usually called "till" or "hard-pan," and (b) modified drift, which is simply assorted or partially sorted drift mate-

* A more comprehensive description of the local formations may be found in the Proceedings of the Municipal Engineers of The City of New York for 1911 under the title: "The Geology of New York City and its Relation to Engineering Problems." A still more extensive discussion of the geology of the surrounding region may be found in Bulletin 146, N. Y. State Museum, Part I. A good geological map and accompanying explanatory text on the geology of New York City is issued by the U. S. Geological Survey as Folio No. 83.

rial such as gravels, sands, silts, clays. The former (a) represents deposition directly from the ice at its margin or beneath the ice mass without enough water action to rework or assort the material. It therefore contains boulders, pebbles, gravel, sand and clay, all mixed together in a most complex way. Such ground is almost always compact and rather impervious in comparison to the other type. Till and assorted materials are commonly closely associated. It often happens that one type passes rather suddenly into the other laterally, or that one type lies beneath the other at the same point.

The modified drift of the district has in the process of its accumulation suffered chiefly a separation of the fine from the coarse particles. In most cases the fine matters that help to make till dense and impervious has been washed out and deposited elsewhere in standing waters as silt and clay. As a result, most modified drift deposits are made up largely of sands and gravels, are very pervious, and carry great quantities of water. Such deposits furnish the building sands of the New York market, such as " Cow Bay sand."

Modified drift is generally readily penetrated by simple exploratory wash boring equipment, while till is usually troublesome because of the occurrence in it of random boulders.

The accumulation of drift material represents a rather complex process with advance and retreat of the ice and with variable assorting action, so that in most of the thicker deposits both types occur. Explorations should show how much of it is till and how much is modified drift.

MANHATTAN SCHIST

This is primarily a recrystallized sediment of siliceous type. It occurs as a nearly black or streaked, micaceous, coarsely crystalline, strongly foliated rock. The chief constituents are biotite, muscovite and quartz. Feldspar, garnet, fibrolite and epidote also occur in large quantity. Occasional streaks or masses are hornblendic instead of micaceous. Pegmatite veins and lenses and dykes are also extremely common in some localities, making up a considerable proportion of the formation. They are of igneous and aquæo-igneous origin.

It is essentially a quartz-mica schist. But it is almost everywhere very coarse textured and hardly ever exhibits the

fine grained, uniform structure of typical schist. Its abnormal make-up—the predominance of biotite and quartz—is the best defense for its petrographic classification. The abundance of mica makes it a tough rock but not very hard. Joints and fractures formed in later movements are not healed and zones of bad shattering are susceptible to considerable decay. These crushings are sufficiently common to encourage borings to tap their content of water for small family use in suburban districts; but they do not represent large circulation in any case. On the whole, the rock if fresh is good and durable. It may, though rarely, carry considerable sulphide. Practically all of the strictly original sedimentation marks are destroyed by metamorphism. The formation has great thickness, but because of the destruction of original bedding lines by recrystallization and additional complication by most complex folding, shearing, crushing and faulting, the structure can not fully be unraveled and the thickness can not be estimated with any approach to accuracy of detail. But there is probably a thickness represented of several thousand feet.

This is the principal bed-rock formation of Manhattan island.

INWOOD LIMESTONE

Inwood limestone or dolomite. This formation lies beneath the Manhattan. It is everywhere coarsely crystalline either massive or strongly bedded, often very impure with development of secondary (recrystallized) mica (phlogopite) and other silicates, especially tremolite. It is essentially a magnesian limestone or dolomite in composition. There is an occasional quartzose bed in the midst of the limestone. The upper beds are most charged with mica and occasionally beds attacked by alteration have much green, flaky chlorite. There are occasional interbeddings of limestone and schist as a transition facies.

The coarser grades upon exposure to weathering readily yield by disintegration to a lime (calcite) sand resembling roughly an ordinary sand in general appearance. At Inwood, the type locality, this disintegration is so pronounced that great quantities are readily shoveled up and used for various structural purposes in the place of other sand. This dolomite is especially liable, as now shown by extensive explorations, to

serious decay to great depth. The underground circulation seems to attack the micaceous beds with great success and in some places the residue after this solvent action is of the consistency of mud. A nearly vertical attitude of the beds no doubt encourages such action.

The thickness probably varies, but in many places where there is only a narrow limestone belt it is due more to shearing or faulting out than to original thinning. The most satisfactory estimates are based on the explorations at the Harlem river. They indicate an approximate thickness of 750 feet. But in all cases either the margins are obscured or there is possibility of faulting to modify measurements. There are no fossils. Weathering and erosion has almost everywhere developed valleys or depressions especially small tributary valleys in all formations, but as pointed out years ago by Professor Dana the principal valleys prevailingly coincide with the limestone belts.

FORDHAM GNEISS

The lowest and oldest, as well as the most complex in structure of all the rock formations is essentially a series of gneisses. Cutting these gneisses as intrusions of various forms are a number of more or less distinctly igneous types. They range in form from small dykes to large batholithic masses, and in composition from acid pegmatites and granites to medium basic diorites. The pegmatites are numerous and abundant but they are nowhere of sufficient prominence to be regarded as a distinct formation. Two of the igneous intrusions, however, are strongly developed within the City and in certain localities occur to the exclusion of all other members. These deserve separate treatment in work of this kind because they have very characteristic qualities of behavior. These two special members are known locally as the Yonkers gneiss, and the Ravenswood grano-diorite.

As intrusives, of course, they are both younger than the complex series of metamorphosed beds into which they are injected.

The older portion—always referred to locally as the Fordham gneiss proper—consists of a series of banded gneisses of various sorts and a variety of interbedded schists, quartzites, and limestones—all together forming the metamorphic

basal complex at the bottom of the geologic column in this district. It was originally a series of sedimentary beds. There is nothing known here that is older. It is regarded by geologists as the equivalent of the *Grenville series* of the Adirondacks and Canada.

No single type and no single characteristic can be given as a simple guide to the identification of this formation. The prevalence of certain varieties or groups of these and the strongly banded structure give a certain degree of character that forms a reasonable working basis. The formation includes banded granitic, hornblendic, micaceous and quartzose gneisses; mica, hornblende, chlorite, quartz and epidote schists; garnetiferous, pyritiferous, graphitic, pyroxenic, tremolitic, and serpentinous limestones, ophi-dolomites, serpentines and quartzites. This is the basal series. But it is complicated by a multitude of bands of granitic and dioritic gneisses that represent injections of igneous material at a time sufficiently remote to be subjected to most of the early metamorphic modifications. The equally abundant occurrences of quartz stringers and pegmatite lenses, though of later origin, can not be separated from this complex mass, and the whole must be regarded as a physical unit. The occurrence of interbedded limestones and quartzites together with a variety of comformable schists and banded rocks, marks the formation as essentially an old recrystallized sediment.

No member of this older unit of the basal complex is sufficiently prominent to indicate a great break or change up to the time of the first great dynamic movements and igneous outbreaks. The following comparatively constant members are sometimes persistent enough to be considered formational units, but even more commonly are obscure as to boundaries or are of too small development to map separately.

(a) *Banded Gneiss.* Granitic and quartzose black and white banded gneisses and schists of very complex composition and structure. Regarded as the "typical Fordham."

(b) *Interbedded Quartzite.* Always a quartzite schist and always exhibiting conformity with the banded gneisses and schists. This is regarded as probably the uppermost member.

(c) *Interbedded Limestones.* Crystalline. Interbedded, very impure, serpentinous and tremolitic, granular dolomites,

usually 2 to 50 feet thick, possibly reaching a thickness of more than 100 feet in a few cases.

(d) *Older Intrusives.* Variable types, mostly gneissoid granites or diorites.

Many are of very obscure relations. The line of close distinction between recrystallized sediment, segregations accompanying that change, and true igneous injection can not be drawn.

THE YONKERS GNEISS

This is a biotite granite in composition but with a distinct foliation shown especially by the mica flakes. It is therefore because of the structure, to be classified either as a granite gneiss or a gneissoid granite, dependent upon the origin of the foliation. This is commonly regarded as a metamorphic effect and the rock is accordingly called a gneiss—Yonkers gneiss as a locality designation because of its large development in the Yonkers district.

It is a rock of very granular habit, with an abundance of quartz and microline and disintegrates under weathering to a residuary sand. It is light colored, usually light pink, and rather uniformly foliated but not at all banded and rarely streaked. It is of fairly uniform quality and is regarded as a good type of rock unless excessively weathered.

THE RAVENSWOOD GRANO-DIORITE

This is another intrusive of similar origin and age as the Yonkers gneiss. But it is more variable. It is generally slightly foliated and carries enough basic, dark colored, mineral constituents to present a grayish color even in the more acid varieties. The mineral variation is considerable—some varieties having the mineral proportions of a typical granite—others of a typical diorite, and there are all gradations between. For this reason largely it is called a grano-diorite. At the time of its intrusion, large blocks of the older banded gneiss (Fordham proper) and associated layers were partially digested (fused) into the igneous mass. Occasional traces of such blocks can be seen in the grano-diorite and still more commonly such fusion is indicated by certain abnormal minerals such as an abundance of garnet in the grano-diorite. Its

most typical development is in Long Island City and in Ravenswood, from which its gets its local name.

This formation is one of the most substantial in the City.

It was found that in New York City the six above described formations were sufficient basis for mapping along the conduit lines, in both the preliminary and the final studies.

Structural Features

These old rock formations, constituting the floor of New York City, are complicated by folding and faulting and igneous intrusion and metamorphism to such extent that in some places these conditions are more important than the identity of the rock itself. It has been necessary to make detailed cross-sections of certain localities showing these structures. The places requiring extra exploration have all been of more complicated structure than usual. For a working understanding of the local geology it is necessary particularly to appreciate the character of folding and faulting in the district.

FOLDS

The folds of the ancient rock floor formations are complicated and variable and sometimes obscure. Everywhere the Manhattan schist and Inwood limestone and Fordham gneiss occur in strips lying more or less persistently parallel with each other. A strip of Inwood limestone a few hundred feet wide is usually bounded on one side by Fordham gneiss and on the other by Manhattan schist. This succession is repeated so often that there is no doubt whatever that it is of the normal order. But also the formations almost everywhere indicate that they are highly tilted and often actually stand on edge. They were not originally deposited in this position, but have been subsequently forced into such position by lateral thrusts which crumpled the beds together into a series of folds. Long continued erosion, ages ago, removed the most exposed portion, and only the stumps of the original folds remain. Therefore, each strip of limestone marks the limb of a fold as it comes to the surface, and one should be able to reconstruct the curve that it used to make, now an imaginary arch in the air coming down and passing below the surface again over beyond the adjacent

ridge of gneiss. One may follow the beds as they extend down some hundreds or thousands of feet below the surface, until turning upward again on the other side of the trough they finally reach the surface as in the first case. The whole proceeding is neither obscure nor difficult, and it is an absolutely necessary step to take if one wishes a working understanding of the structural relations of these older formations. A little careful observation will then convince one that the formation found within the limestone arches is always Fordham gneiss, and that the formation found within the limestone troughs is always Manhattan schist. Such distribution and relation can have only one meaning, i. e., the Fordham is the basal and oldest member of the series. Wherever Manhattan schist is the surface formation one can find the Inwood limestone and Fordham gneiss below if only the exploration be carried deep enough. On the other hand, no matter how deep the Fordham gneiss is penetrated no other formation has yet been found beneath. Folding so closely repeated, such as is exhibited in these rocks, is never perfectly symmetrical. In New York City, sometimes the beds are tilted even beyond the vertical (overturned). If locally they seem to be very differently related, knowing the standard succession, there need be no difficulty at all in detecting the occurrence as abnormal. There are no flat-lying beds. Large areas of a single formation, such as of schist in the eastern portion of The Bronx or in western Manhattan, means that the crests of the underlying limestone and gneiss do not reach to the surface and consequently the whole surface is schist. But structurally the schist of those areas is folded into troughs and arches just as systematically as are the formations where the whole series is exposed. The series of folds has been formed by thrusts that seem to have acted from the southeast, and consequently the axes of the folds trend northeast and southwest. All of the belts or strips of these formations, therefore, also have the same trend. Furthermore, the axes of the folds pitch slightly to the southwest, so that the tendency is for the older formations to pass beneath the surface southward.

If one follows a particular ridge of gneiss from north to south it will generally be found that it becomes gradually narrower and lower till it finally passes beneath the limestone

and this in turn passes beneath the Manhattan schist. All of these folds are old—older than the folding of the Appalachian mountains.

FAULTS

An additional source of complexity lies in the fracturing and displacement of two portions of a formation which originally lay immediately adjacent. This is known as faulting. When this occurs the regular succession may be abruptly changed. In some instances a whole formation is cut out, and two that normally do not belong together are brought into contact. Such an effect is brought about between Blackwell's island and Manhattan, where a tunnel at 72nd street shows that Manhattan schist lies in contact with Fordham gneiss. Most of the known faults have taken place along breaks that trend northeasterly with the structure, but others running northwesterly across the formational structure are also well known. Fault planes are places of weakness which, if not rehealed by deposition or recrystallization, become the principal courses of water circulation. This has a double bearing. It marks out the places where deeper decay than usual is to be found, and it also marks the chief source of water-supply for wells drilled into the crystalline rock.

Both folding and faulting have taken place in different geologic periods. In the case of faults, the older ones are more likely to be rehealed and to be about as impervious and durable as any other portion of the rock, while the latest ones are usually not healed and their broken or open character encourages circulation and consequent solution and decay effects.

The greatest of the local faults is probably that following the course of the Hudson river. The west side of the Hudson is apparently dropped down with respect to the east side. The position of the fault is such as to defy direct observation, but general regional relations favor its existence.

A fault that has developed much broken rock by its movement and that is not rehealed completely is called a "crush zone." It is a zone of excessive weakness as a rule—in part, because the rock is broken and in part because there is increased water circulation and generally much decay.

Between the Manhattan schist and Inwood limestone there is no time break. The beds follow one upon the other in normal order. But between the Fordham gneiss and the Inwood limestone there may be more of an interval. The limestone does not always lie next to the same beds of gneiss. This leads to the belief that these two formations are not perfectly conformable.

PHYSIOGRAPHIC HISTORY

Present surface features are everywhere the result of the orderly work of a few well-known geologic agencies acting on the combination of formations that in the vicissitudes of past geologic time have been developed as the rock floor of a region. The agencies of most consequence are the atmosphere, surface heat, water and internal forces. The activities of most importance are atmospheric weathering, changes of temperature, wind action, the erosive action and transportation work of water, and shifting of levels caused by internal dynamic forces. Different regions have back of them a different history which is preserved permanently in the condition and relations and structures of its rock floor formations, and, however long and persistently the agencies of erosion may work, the resulting relief will always be consistent with these factors. On the other hand, if one knew all of the niceties of relief character that could arise from every variety of rock and rock structure, it ought to be possible to work backwards and interpret underground conditions from the physiographic features of the surface alone.

For New York City and adjacent districts the starting point of the present surface form dates back to Cretaceous time. The continent stood then for an exceedingly long time only moderately elevated above sea-level, and remained stable so long that nearly everything was worn down to a simple plain of erosion so very flat that it is always referred to as the "Cretaceous peneplain." On the divides between the greater stream courses of that time, of course, there were occasional areas that had not yet been worn down to the general level. These patches were either of harder rock type or so distant from the best channels of erosion that they lagged behind in the general

reduction of surface. Such an area represented the present Catskill mountains. But none of our present-day relief features about New York City were in existence, except potentially in the differences of structure of the rock floor of that time. That ancient plain existed somewhat above the level of the average elevation of the tops of our highest hills in southeastern New York. This plain drained into the Atlantic, where the waste that the streams carried accumulated as Cretaceous sands and shales. As a whole it must have reached present sea-level at about the East river and the Upper bay and must have risen gradually inland for several hundred miles. The streams flowed sluggishly over silts and sands and heavy residuary soil which obscured the rock floor everywhere. The underlying rocks, therefore, had no control of the stream courses as they flowed on the alluvial deposits there.

But at the close of Cretaceous time the whole continental margin was elevated at least several hundred feet, perhaps inland as much as 2,000 feet, above its former level and warped and tilted somewhat unevenly toward the sea. Then the work of erosion was actively renewed (rejuvenated).

All of the relief that we now see has been carved out of that old plain by the erosive activity of the streams and other surface agencies since that time. Portions that now form the hilltops and mountain tops of this district and adjacent ones were in the beginning of this epoch constituent parts of the rock floor of the peneplain. As soon as streams had cut down through their alluvium to bed-rock again and this obscuring mantle was removed, they began to lay out the lines on which present-day relief has been developed. The making of valleys may be considered the primary work of a stream. This is accomplished by removing the disintegrating rock and soil as it is formed on the rock floor. Where no such disintegration is taking place little work can be done; wherever decay is rapid there it is also possible for much work to be done by the stream, and by the removal of debris the beginnings of a valley are made. Thus it happens that streams have great facility in finding and following the softest or most easily attacked lines or zones or belts or formations—a fact that is of immense practical value to the geologist and engineer. Their distribution is studied with great care. They furnish clews to weaknesses

or other structures that are too obscure for any other agency to find. In the course of time, after the main streams and tributaries have had opportunity to discover the easiest lines, the structure of the rock floor of a region like New York is indicated by them almost as clearly as the lines of a geological map.

When the continent was elevated at the close of Cretaceous time and streams were rejuvenated and valley-making began anew, the streams that were already in existence on the old peneplain surface soon removed the alluvium that covered the rock floor and discovered a rock structure inconsistent with the courses they then had. Some of the master streams were large enough to establish channels that kept them in their original courses, in spite of the fact that later they found themselves crossing hard and soft, very resistant and very easily destroyed formations. Such behavior is credited to the Hudson. But most of the tributary or smaller streams of all kinds shifted into the prevalent structural lines. The hard and soft beds, the trend of folds, the strike of strata, the position of fault zones, the areas of harder igneous or crystalline rock were discovered. Valleys were made where the softer ones are, ridges were left where the harder ones are, and surface relief took on the beginnings of present-day lines. Only the hills were not so high above the valleys, because the valleys were not yet cut so deep below the level of the old peneplain. As would be expected, the main ridges in the areas of the older crystalline rocks, including the Manhattan-Inwood-Fordham series, developed rounded outline and a trend northeast and southwest parallel to their structure. In the Triassic rocks on the west side of the Hudson there came to be prevalent a series of eastward facing cliffs surmounted by the very uniform ridges that gradually die away to the westward in gentle dip slopes only to be succeeded by still others of similar form, a form that is accentuated wherever igneous intrusions occur. The lower Hudson exhibits such character. In the Cretaceous and Tertiary strata of Long Island the steeper sides face northward and the gentler slopes are toward the sea. Long Island Sound valley, which is now simply drowned, is one of this type. The northern margin of Long Island constitutes a steeper northward facing slope while the gentle southern slope reaches to the sea.

If the continent were to stand stable for long enough time the whole region would once more be worn down to another and lower peneplain. The tendency would be for the large streams, which work rapidly, to cut down their valleys to approximately the final level first. Additional work then widens them into flat-bottomed valleys which, by further widening and extension, mark out the new peneplain position with considerable definiteness. The position of it below the original Cretaceous peneplain would depend upon the elevation of the continent above the sea. At least one such level was marked out in Tertiary time. The continent stood somewhat lower than now. The streams reached grade and began developing wide flat-bottom valleys marking out the new peneplain. But before it was a third finished a second elevation affected the region, the whole continental border was raised a few hundred feet and again warped or tilted seaward, the streams were rejuvenated and began to cut notches into the bottoms of their flat-bottomed valleys, making valleys within valleys everywhere.

These processes and principles are the keys to an understanding of local surface features. The rock floor in New York is a surface developed in this way. It has a form perfectly consistent with such stages of history, such selective activity of erosion agents and such structural control. Its most perfect development had been reached in Pleistocene time, just preceding the Ice age.

But just before the glacial occupation the continent was again greatly elevated, the largest streams cut deep, narrow gorges, which were incomplete when the continental glacier began to cover it. The ice scraped off the exposed prominences, plowed up the residuary soil, carried in immense quantities of waste rock from more northerly areas, and finally withdrew leaving the mixed lot choking the valleys, obscuring the escarpments and covering most of the rock floor. It has done three things that modify the perfect stream erosion topography that had previously been developed. (a) It removed much loose soil, (b) it gouged out or broke off a good deal of more substantial rock, actually widening and deepening some of the gorges and valleys wherever their courses encouraged ice flow, and (c) it has piled up glacial drift in such a promiscuous way that many of the finer relief lines are obscured.

THE GEOLOGIC MAP

The areal distribution of geological formations along the proposed lines in New York City has been shown on the accompanying map (Sheet 18). Outcrops are shown in solid colors and the estimated extent of formations is indicated by line patterns of different colors.

In general the kind of rock to be found at tunnel depth will be the same as at the surface, as indicated on the map for each point. Such error as there is arises from these two causes: (a) Uncertainty about the exact position of the contact lines between formations along certain stretches of ground (usually due to heavy drift cover), and (b) the dip and pitch of the rock.

In the first case (a) where the drift is particularly heavy, it is sometimes impossible to fix a contact line accurately from surface features alone.

In the second case (b) it must be appreciated that nearly all of the formations dip eastward at a very steep angle, so that a formation would usually be found to extend a little further east at depth than at the surface. And also all formations pitch southward, so that they would be found to extend considerably further south at depth than their surface outcrops. This angle of pitch is from 10 degrees to 30 degrees.

In nearly all these cases, however, the obscurity of the actual surface boundaries is as great a source of uncertainty as the effect of dip and pitch, so that the boundaries as mapped may be considered sufficiently accurate for this comparative study of the lines.

It is worth noting that the rock at the proposed depths of tunnels would be, as a rule, more substantial than at the surface. But there are several places on all of the lines where the exact condition is unknown at the surface as well as at depth. The chief points of this character will be noted in a later paragraph.

SPECIAL COMPARATIVE STUDY OF THE TRIAL LINES

A comparison of the three lines submitted as the basis of examination—(a) the westerly one, (b) the central one, (c) the easterly one (see accompanying map, Sheet 18), as

to rock formations likely to be cut by them, furnishes the following figures:

LINE A—GOING SOUTHWARD FROM HILL VIEW RESERVOIR

6,200 feet—Yonkers gneiss—good rock.
1,400 feet—Fordham gneiss.
1,400 feet—Probably largely Inwood limestone with one weak zone (at Van Cortlandt lake).
5,600 feet—Fordham gneiss—good rock.
2,400 feet—Near contact with limestone, probably in gneiss.
1,600 feet—Crossing Harlem river—Inwood limestone.
4,000 feet—Inwood limestone—probably fairly good rock.
800 feet—Inwood limestone—probably containing bad zone to Speedway.
16,400 feet—Manhattan schist (to 135th street).
2,000 feet—Along contact between schist and limestone.
4,200 feet—Inwood limestone with one weak zone (to south end of Morningside park).
12,800 feet—Manhattan schist—probably good quality (to south end of Central park).
21,000 feet—From Central park to East river—no outcrops—mostly Manhattan schists at tunnel depth. Condition largely conjectural — probably mostly good rock with occasional weak zones.
6,000 feet—Manhattan island to City Hall, Brooklyn—Containing an unknown zone in the East river and unknown quality of rock in Brooklyn.

SUMMARY OF LINE A

6,200 feet—Yonkers gneiss.
7,000 feet—Fordham gneiss.
2,400 feet—Contact (probably in gneiss).
12,000 feet—Inwood limestone.
2,000 feet—Contact (probably in limestone).
29,200 feet—Manhattan schist (good).
21,000 feet—Estimated Manhattan schist (fair).
6,000 feet—Almost unknown.
85,800 feet—Total.

Line B—Going Southward from Hill View Reservoir

8,000 feet—Yonkers gneiss—good quality.
13,000 feet—Fordham gneiss—good quality.
6,800 feet—Inwood limestone—probably mostly in fair condition, except at two points (to Cromwell avenue).
6,600 feet—Inwood limestone—unknown condition, but probably largely poor (to Harlem river).
600 feet—Inwood limestone—unknown condition (Harlem river).
4,600 feet—Inwood limestone—unknown condition—probably fair (to Mount Morris park).
800 feet—Manhattan schist—good quality.
800 feet—Probably Manhattan schist—unknown quality.
2,800 feet—Inwood limestone—unknown condition—probably at least one bad zone (to 106th street).
12,000 feet—Manhattan schist along Central park—good.
8,600 feet—To Broadway—Manhattan schist (little known except from tunnels already made).
14,000 feet—To East river—probably Manhattan schist (same as Line A).
6,000 feet—Manhattan island to City Hall, Brooklyn—uncertain condition (same as on Line A).

Summary of Line B

8,000 feet—Yonkers gneiss—good quality.
13,000 feet—Fordham gneiss—good quality.
21,400 feet—Inwood limestone—variable quality.
12,800 feet—Manhattan schist—good quality.
23,400 feet—Estimated Manhattan schist—fair.
6,000 feet—Almost unknown.
84,600 feet—Total.

Line C—Going South from Hill View Reservoir

6,000 feet—Yonkers gneiss—good rock.
17,400 feet—To Webster avenue—Fordham gneiss—good rock.

5,000 feet—Along contact between limestone and gneiss.
9,800 feet—To 138th street—Inwood limestone with probably two bad zones.
1,800 feet—To Bronx kills—along contact between limestone and gneiss—uncertain quality.
600 feet—Across Bronx kills—mostly in limestones containing a fault zone—probably bad ground.
6,400 feet—Crossing Randall's and Ward's islands and Little Hell Gate—nearly all is Manhattan schist of good quality.
1,000 feet—Crossing Hell Gate—Inwood limestone.
1,200 feet—Crossing Hell Gate—Fordham gneiss of good quality.
1,800 feet—Astoria point—probably Fordham gneiss of good quality.
1,000 feet—Crossing another limestone belt.
1,000 feet—To Vernon avenue—Fordham gneiss of unknown quality containing one fault zone.
7,000 feet—To Nott avenue—Ravenswood grano-diorite—good rock.
2,800 feet—To Borden avenue—probably Ravenswood grano-diorite.
18,400 feet—To Fort Greene park, Brooklyn—almost wholly unknown but probably contains 5,000 or 6,000 feet of poor ground.

SUMMARY OF LINE C

6,000 feet—Yonkers gneiss—good quality.
17,400 feet—Fordham gneiss—good quality.
6,800 feet—Along contact between limestone and gneiss (questionable).
12,400 feet—Inwood limestone—with several bad zones.
6,400 feet—Manhattan schist—probably good quality.
3,000 feet—Fordham gneiss—probably good quality.
1,000 feet—Fordham gneiss—unknown quality.
9,800 feet—Ravenswood grano-diorite—mostly very good rock.
18,400 feet—Almost wholly unknown.
81,200 feet—Total.

TABULATED SUMMARY—TYPES OF ROCK FORMATIONS

	Line A (West)		Line B (Central)		Line C (East)	
	Feet	Per cent.	Feet	Per cent.	Feet	Per cent.
Yonkers gneiss	6,200	7.2	8,000	9.4	6,000	7.3
Fordham gneiss	7,000	8.1	13,000	15.3	21,400	26.3
Contact zones	4,400	5.1	.....	...	6,800	8.3
Inwood limestones	12,000	13.9	21,400	25.3	12,400	15.2
Manhattan schist	50,200	58.5	36,200	42.6	6,400	7.8
Ravenswood grano-diorite	.....	...	.....	...	9,800	12.0
Unknown	6,000	7.0	6,000	7.0	18,400	22.0
Total length	**85,800**		**84,600**		**81,200**	

SUMMARY OF QUALITY

	Line A		Line B		Line C	
	Feet	Per cent.	Feet	Per cent.	Feet	Per cent.
Good rock, 1st grade	42,400	49.4	33,800	40.0	39,800	49.0
Probably fair, 2nd grade	30,800	35.9	34,800	41.1	13,600	16.7
Probably poor, 3rd grade	6,600	7.7	10,000	11.8	9,400	11.6
Almost unknown	6,000	7.0	6,000	7.1	18,400	22.7
Totals	**85,800**	**100.0**	**84,600**	**100.0**	**81,200**	**100.0**

ARGUMENT ON CHOICE OF LINE

In judging the quality of rock and its suitability for this conduit the factors of most weight are the same as those repeatedly mentioned in connection with other portions of the Catskill Aqueduct line. That is, in brief, that the harder crystalline rocks of the Fordham gneiss and Manhattan schist types wherever known to be free from fault crushing and surficial weathering are the best grade; that the more heavily buried areas of these rocks, together with those limestone areas that are known to be the most substantial of that class, should be regarded as fair or second grade; that the more obscure areas of limestone and all portions crossing faults or rivers or crush zones in any rock must be regarded as poor or third grade. This rating is based wholly on rock character and without any consideration of cost of construction.

From the above it is clear that Line A has more "first grade" rock than either B or C and less "third grade" ground.

Line C has three times as much "unknown" ground as either B or C and less "first" and "second grade" rock.

In other words, the three lines are estimated:

	Line A Per Cent.	Line B Per Cent.	Line C Per Cent
First grade rock	49.4	40.0	49.0
Second grade rock	35.9	41.1	16.7
First and second grades together	85.3	81.1	65.7
Third grade rock	7.7	11.8	11.6
Unknown ground	7.0	7.1	22.7

In addition to these differences of quality, it appears from a study of the areal geology along the respective lines that a tunnel would pass across limestone contacts from one formation to another six times on Line A, four times on Line B, and seven times on Line C. These may all be considered points of probable weakness.

All of the lines cross belts of well-known weakness believed to represent fault zones. Line A crosses three such zones, Line B crosses two, and Line C crosses at least three.

Furthermore, all of the lines cut limestone for greater distances than seems desirable or necessary. The weakest ground and the most uncertain quality of ground that can be mapped falls within the limestone areas. In this respect Line A with 13.9 per cent. of limestone ground is preferable to Line B, with 25.3 per cent., or Line C, with 15.2 per cent.

From the above it is apparent that Line C is least defensible. Line A has some advantage over both of the others, especially in quantity of first grade rock, together with low amount of the known poorest grade and small extent of the so-called "unknown" ground.

The chief advantage of Line A over Line B lies in its much smaller limestone area (12,000 feet vs. 21,400 feet or 13.9 per cent. vs. 25.3 per cent.), and the chief advantage of Line A over Line C lies in its much smaller amount of "unknown" ground (6,000 feet vs. 18,400 feet or 7.0 per cent. vs. 22.6 per cent.). On these grounds Line A is the least objectionable of the three lines proposed.

But it is also clear from an examination of the field, as is shown on the accompanying map (Sheet 16), that it is possible to avoid some known objectionable features or certain parts of them and materially improve the figures by shifting the line to a sort of compromise position between Line A and

Line B. This compromise line, or the trial lines from which the final tunnel line may result, should follow as closely as possible the gneiss and schist ridges and should avoid the limestone areas and known weak zones wherever possible.

DEPTH OF TUNNEL

The rock formations in general at the required depths are no more objectionable on Manhattan island or in The Bronx than at other localities on the Southern aqueduct. There are weak places and crush zones to be crossed and some of them cannot be avoided by any possible manipulation of the line, but these most questionable spots constitute only a small portion of the whole distance. The depth most suitable must depend chiefly upon the depth necessary at the worst spots.

EFFECT ON CONSTRUCTION IF LINES ARE SHIFTED

The question is best answered by reference to the geological map. It will be noted especially that the belts of the different rock formations are usually narrow, and that they run nearly parallel to the average direction of the lines. Therefore a shift of line to no great distance would at many points place it within an entirely different formation. It is also notable that all of the lines run along or near the contacts between formations for long distances. At such points a very small shift would wholly change the type of rock and rock quality. Some shifting is desirable.

In general it may be assumed that the limestone belts would be easiest and cheapest to penetrate wherever they are fairly substantial, but they undoubtedly also contain the greater proportion of weak and troublesome ground and must be considered least desirable from the standpoint of maintenance and durability. The gneisses are probably most expensive to penetrate and the schists, medium. Both are more expensive than limestone but both are more likely to prove acceptable for other reasons.

The question of shifting the lines is a complicated one and hinges more upon rock condition, durability, and location of weak zones than on any possible cost.

ADVISABLE CHANGES IN LINES

None of the suggested lines are defensible from a geologic point of view for the reason that a much better one may be obtained by no very serious shifting.

In the general consideration of relative advantages of different possible locations of the line, it is believed that the following large features are of most immediate importance:

(1) The ridges as opposed to the valleys.

(2) The hard formations as opposed to the softer ones.

(3) The crossing of few contacts as opposed to crossing many.

(4) The location well within a formation as opposed to location along a contact.

It is distinctly preferable from a geologic standpoint (1) to follow the ridges, (2) to keep in the hard formations, (3) to avoid many changes from one formation to another, (4) to keep away from contact lines, and (5) to avoid weak zones, if possible, or cross known troublesome zones at the most advantageous point.

RECOMMENDATIONS OF NEW LINES F, G, H, I

The original lines A, B and C are marked on the map in blue (Sheet 18). In addition several trial lines are sketched in yellow, any one of which would give better geological conditions than any of the three original lines. The newly suggested trial lines differ from each other chiefly in the points at which they cross the limestone belts and weak zones. In all of them the central idea has been to follow the gneiss and solid ridges as persistently as possible. All unite at Central park and are intended to follow Fifth avenue, Broadway, the Bowery and Market street to East river along one of the original lines. North of Central park they differ from the original lines. The westerly one crosses the Harlem river at 176th street and may be designated Line F. The easterly line may also cross the Harlem river at 176th street and may be designated Line G; or it may continue southward and cross the Harlem at 155th street. It will then join the first one in the vicinity of 144th street and is called Line H. The alternative easterly one which crosses the Harlem at 155th street and follows Seventh avenue to Central park is Line I.

Details of rock conditions along these lines are as follows:

LINE F—(WESTERLY) BEGINNING AT HILL VIEW RESERVOIR

7,600	feet—Yonkers gneiss—good quality.
15,000	feet—Fordham gneiss—good quality.
2,000	feet—Fordham gneiss—probably second grade.
1.200	feet—Harlem River crossing—partly limestone—third grade.
14,800	feet—Manhattan schist—good quality.
1,600	feet—Manhattanville crossing—third grade—some limestone.
2.600	feet—Manhattan schist—good rock—through Morningside park.
800	feet—At south end of Morningside park—perhaps some limestone—second grade.
1,400	feet—Manhattan schist—good—to junction.
12,000	feet—Manhattan schist—along Central park—good.
20.600	feet—To East river—Manhattan schist—less known—(fair) (second grade).
6,000	feet—To Brooklyn—" unknown."
85,600	feet—total.

LINE G

8,400	feet—Yonkers gneiss—good rock.
17,600	feet—Fordham gneiss—good rock,

which brings it to the Harlem river where the other line (F) is joined. Although the line is about 1,400 feet longer, it avoids some low ground (200 feet) along the east bank of the Harlem river, some of which may be in poor condition. Total length of line, 87,000 feet.

LINE H

8,400	feet—Yonkers gneiss—good quality.
23,800	feet—Fordham gneiss—good quality—to Harlem river.
1,000	feet—Crossing Harlem river—probably fault zone in gneiss.
800	feet—Fordham gneiss—good quality.

1,000 feet—Limestone—second grade.
1,200 feet—Manhattan schist—good quality—to junction with the first line (F) at 145th street.

From this point the line is the same as F and G. Its chief advantage is the great distance which it has in Fordham gneiss.

Total length of line, 85,600 feet.

Line I

8,400 feet—Yonkers gneiss—good quality.
23,800 feet—Fordham gneiss—good quality—to Harlem river.
1,000 feet—Crossing Harlem river—probably fault zone in gneiss.
4,400 feet—Fordham gneiss—good rock—to 135th street.
4,600 feet—Inwood limestone—probably fair—second grade.
2,000 feet—Inwood limestone—probably poor quality—third grade.
1,000 feet—Manhattan schist—good quality.

At this point the line unites with Line F. Total length of line, 83,800 feet.

A tabulation of these figures indicating estimated extent of rock types is given below:

	Line F Feet	Line G Feet	Line H Feet	Line I Feet
Total length of line	85,600	87,000	85,600	83,800
Length in Yonkers gneiss	7,600	8,400	8,400	8,400
Length in Fordham gneiss	17,000	17,600	25,600	29,200
Length in Inwood limestone and marginal contacts	3,600	3,600	3,400	6,600
Length in Manhattan schist	51,400	51,400	42,200	33,600

COMPARATIVE SUMMARY OF TYPES OF FORMATION (COMPARATIVE DISTANCES ARE EXPRESSED IN PERCENTAGES)

	A	B	C	F	G	H	I
Yonkers gneiss	7.2	9.4	7.3	8.8	9.6	9.8	10.0
Fordham gneiss	8.1	15.3	26.3	19.8	20.2	29.9	34.8
Contact zones	5.1	....	8.3	4.2	4.1	3.9	7.8
Inwood limestone	13.9	25.3	15.2				
Manhattan schist	58.5	42.6	7.8	60.0	59.0	49.3	40.1
Ravenswood grano-diorite	....	....	12.0	....	....	....	....
*Too little known to classify	7.0	7.0	22.6	7.0	6.9	7.0	7.1

*Now known to be chiefly grano-diorite.

As a group it is especially noticeable that the new lines F, G, H, I, have a very much lower percentage of contact

beds and limestone. The percentages of gneisses have been notably increased, and the unknown and questionable formations have been reduced to approximately the lowest terms.

ESTIMATED SUMMARY OF QUALITY

	Line F Feet	Line G Feet	Line H Feet	Line I Feet
Good rock, first grade	53,400	56,800	54,600	49,600
Fair rock, second grade	23,400	21,400	22,400	25,200
Poor rock, third grade	2,800	2,800	2,600	3,000
Unknown (Brooklyn)	6,000	6,000	6,000	6,000
Totals	**85,600**	**87,000**	**85,600**	**83,800**

In other words, these new lines show:

	Line F Per cent.	Line G Per cent.	Line H Per cent.	Line I Per cent.
First grade rock	62.3	65.3	63.8	59.1
Second grade rock	27.3	24.6	26.1	30.0
First and second grades together	89.6	89.9	89.9	89.1
Third grade rock	3.2	3.0	3.0	3.6
"Unknown" ground	7.0	6.9	7.0	7.1

A comparison on this basis with the original lines A, B, C indicates that these new lines F, G, H, I, make a better showing, especially on first grade rock and that all show decided reduction on the third grade ground.

	A	B	C	F	G	H	I
First grade rock	49.4	40.0	49.0	62.3	65.3	63.8	59.1
Second grade rock	35.9	41.1	16.7	27.3	24.6	26.1	30.0
First and second	85.3	81.0	65.7	89.6	89.9	89.9	89.1
Third grade rock	7.7	11.8	11.6	3.2	3.0	3.0	3.6
*Unknown	7.0	7.1	22.7	7.0	6.9	7.0	7.1

*Now known from explorations to be first grade.

On geological grounds, therefore, it is confidently believed that any one of the new lines (F, G, H, I) would give decidedly better results than any one of the original ones (A, B, C). The poor and the questionable and the unknown ground can not be wholly avoided by any possible line, no matter how roundabout. In these lines, approximately as drawn, the objectionable points are reduced to a minimum with almost no increase in total length of conduit. The objectionable portions are also restricted in large part to the Harlem river, where we already have the experience of the last aqueduct (the New Croton aqueduct) as a guide, and a very few other spots.

General Conclusions

Line I is the shortest possible defensible line. Its chief objectionable feature is a rather long stretch, 6,600 feet of limestone, from 135th street to Central park, upon the quality of which there are no data. It crosses the Harlem River fault probably in gneiss. But it crosses the extension of the Manhattanville fault in limestone.

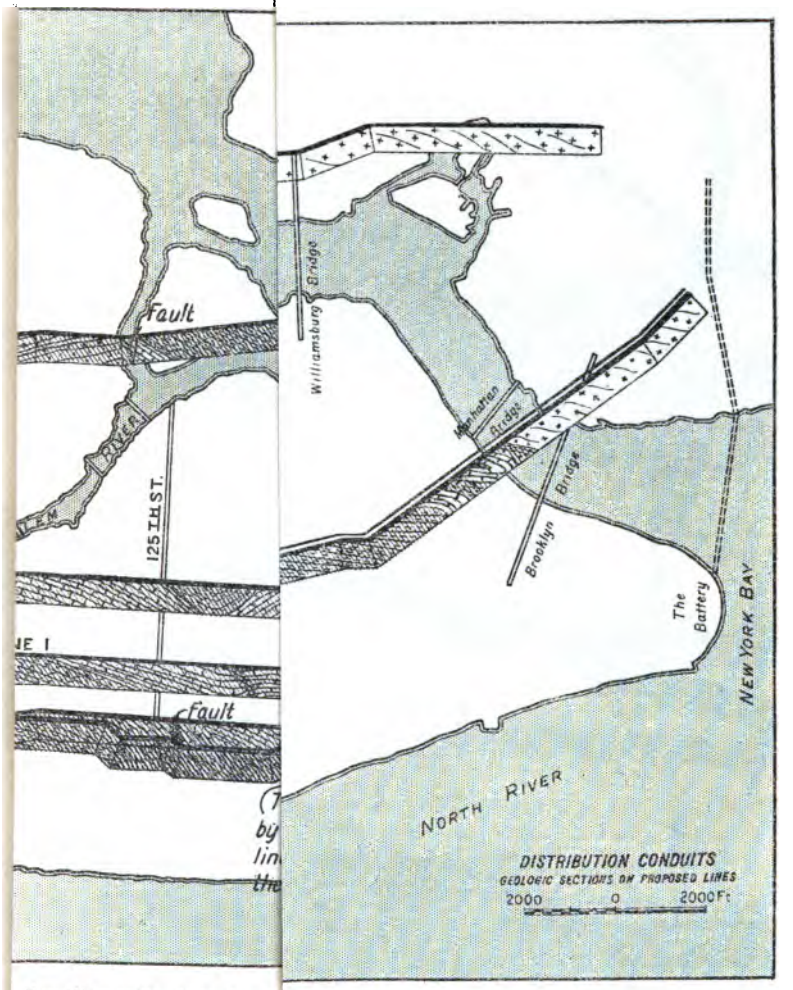
Lines F, G, and H are almost equally defensible. Line G is longest, but is in some respects—especially in following the ridge crests—one of the best possible locations.

It should be appreciated that many other matters, such as municipal works already completed or projected, or matters of engineering practice, are likely to make it necessary to modify any line proposed, and that the final line is more likely to be a compromise, considering all interests.

A graphic representation of the comparative merits of the proposed lines is given in Sheet 5. This is strictly a geologic study. The lines are properly placed on an outline map of the City, corresponding exactly to those drawn on the geologic map, Sheet 18. The geologic formations that each would cut are represented on longitudinal sections which follow each line, and the attitude and structure of each formation are indicated.

REVISED LINES

Subsequently two revised lines based upon the preceding studies were examined to determine preference. Later one of these, or a slight modification of it, was adopted as the one to be explored. It was soon determined on the same reasoning as was applied to the first group of lines that the most westerly line—the line keeping as much as possible within the gneiss and schist ridges—would be the most likely to give satisfactory conditions. By this method of selection the unknown or untested and doubtful ground was reduced to its lowest limits. It was found that nearly all of the very weak spots could be located by inspection on the northern portion of the line, but south of 59th street the question is decidedly more difficult because of the heavy drift cover. No rock outcrops occur south of 30th street, and one is reduced to the evidence of deep borings.



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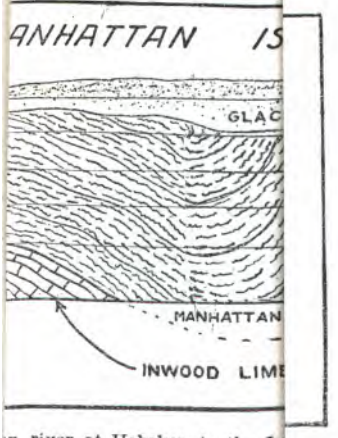

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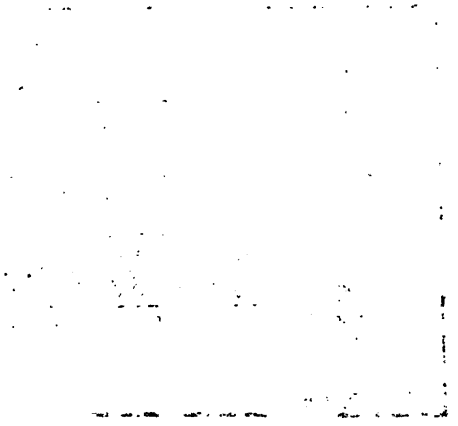


Points for Exploration North of 59th Street

It was soon evident that extensive exploratory work would have to be undertaken for additional data and the following points were selected at which to begin:

(1) The Harlem River crossing, where the distribution conduit line crosses the river just below High bridge (see later description). The only good evidence as to character of rock at this place is from the pressure tunnel of the New Croton aqueduct which crosses the river a short distance above.

(2) The Manhattanville cross valley (125th Street depression). This is the most important cross depression on the Island of Manhattan. It is apparent after a little investigation that the bed-rock floor lies deep, and that if it were not for the drift-filling, the tides would surge through this valley making a direct connection between the Hudson and the East river. It was the least known as to depth and character of any point along the proposed line.

(3) The depression between Morningside and Central park. At that place limestone on the crest of a pitching anticline reaches farther south than on either side and is more deeply eroded. The other zones of large importance are in southern Manhattan, the geology of which was made a special study.

Special Study of the Geologic Conditions South of 59th Street

Below Central park there is now little to be gathered from a study of the present surface. But as far south as 31st street the bed-rock geology is pretty well known from earlier reports and from recent improvements that have exposed the underlying rock. All of this portion is mapped as Manhattan schist except one small area of serpentine at 59th street between 10th and 11th avenues. There is no reason to modify this usage. A careful study of a great number of rock borings from the Pennsylvania Railroad tunnel across Manhattan at 32nd street proves beyond question that bed-rock is Manhattan schist, including almost all known variations and accompaniments, for the whole width of the island along that line.

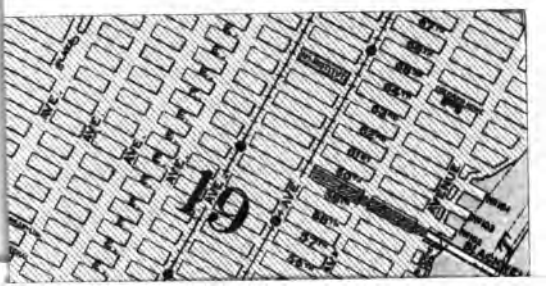
Still farther southward the points that have yielded exact information about bed-rock are less numerous, and below 14th

street are confined to deep borings or an occasional very deep excavation for foundations. Even these sources of information are lacking over large areas. The greater number of borings available are along the water front. Their distribution is such as to indicate that the west side and central portion and southerly extremity of the island are all underlain by Manhattan schist. This is true eastward to the East river at 27th street, and as far eastward as Tompkins square at 10th street and almost to the Manhattan tower of Brooklyn bridge in that vicinity.

To the eastward of these limits, i. e., to the eastward of the line projected from Blackwell's island to the Manhattan tower of Brooklyn bridge, there is a more complicated geology. The borings of the East River water front are decidedly variable. They are certainly not all Manhattan schist of the usual types. Those most unlike the Manhattan are at the same time most like some varieties of the Fordham, and indicate that these formations both occur. The lack of any data in the beginning of this investigation except on the water front made it impossible to draw more than very general lines. Drawn in this way, the lines of course are too straight, but it is certain that they indicate more nearly the actual existing areal distribution of formations than any of the maps now in existence. They indicate a southward extension of the Blackwell's Island belt of Fordham gneiss toward the Manhattan tower of Brooklyn bridge. How much of this anticlinal fold of Fordham actually brings this formation to the surface it is impossible to say, but that it may be expected to be encountered along this line is evident.

On the east side a parallel belt of limestone is indicated and this again is succeeded by a Fordham gneiss area which occupies the rest of the eastern margin. Explorations made along the line of the gas tunnel across East river at 72nd street indicate comparatively narrow belts of limestone there in both the east and west channels. The limited width of limestone at these points, together with the occurrence of two strongly developed disintegration zones, seem to indicate rather extensive squeezing out and faulting of this formation along fault planes parallel to the strike. Such movements are capable of cutting out the intermediate limestone entirely from between

SHEET 6



the schist and gneiss. It is impossible to say, in the almost total lack of data bearing upon the question, how much of such modification exists. The intermediate belt is indicated on the accompanying map (Sheet 6), as a limestone area. At one point at least the limestone does occur in the older borings, i. e., on the southeastern margin of the Manhattan pier of the Manhattan bridge (Bridge No. 3), at the foot of Pike street.

On the Brooklyn side no formations of this series except the Fordham and its associated igneous masses, such as the Ravenswood grano-diorite, have been identified within the area under study. Limestone is reported (Hobbs reference to Veatch) near Newtown creek, a little beyond the eastern margin of the present map.

The East River Area

MANHATTAN SIDE

In all of the area south of 59th street, structural features are even more obscure than the areal geology.

There is no reasonable doubt but that weak zones will be found as frequently in the Manhattan schist portion of this area as on the line north of 59th street, but they can not be indicated as closely. No cross fault of large consequence can be identified, but there is some evidence of a minor zone that should be encountered on Fifth avenue, in the vicinity of 32nd street. The Pennsylvania tunnels and the subway both cross this line and so far as known there were no serious weaknesses developed. There is nowhere any evidence of an important depression like the Manhattanville valley.

It is confidently believed that the problems on this southerly portion of Manhattan are involved chiefly with the longitudinal structures produced by folding and faulting and subsequent disintegration along such zones.

Two trial lines, marked P and Q, were laid out across the East river (see location on map, Sheet 18). From 59th street to the East river there seems to be no reason for a preference between the two lines P and Q. On the Brooklyn side likewise there is no known geological reason for preference. Such basis for choice as is now known relates to the East River channel alone. Since this is regarded as a very difficult section of the

line to explore and probably the most uncertain section to estimate as to condition and consequent depth of tunnel, it would be especially useful to be able to make a decisive selection of crossings at once.

Such evidence as has any bearing upon this question has already been used in formulating the interpretation of geologic structure given in the foregoing sections of this report. If the succession and boundaries of formations as outlined are reasonably close to the actual conditions, it would appear that Line P (the southerly one just above Manhattan bridge) has some advantage over Line Q (near Williamsburg bridge). The chief elements in this advantage are as follows:

(1) It would appear that Line P might be wholly within the Fordham gneiss in the East River section, while Line Q may cross two contacts.

(2) From the evidence of borings made in the East river at 14th street it appears probable that a belt of schist similar to Manhattan schist in quality (whether accompanied by limestone or not there is no direct evidence) lies in the river channel toward the east side and in all probability extends southward in the middle of the river at Williamsburg bridge. This would be cut by Line Q. The uncertainties of this association are of sufficient importance to throw the balance of present choice toward Line P.

(3) If the theory that the East River course is due chiefly to zones of weakness following fractures or faults is true, their possible comparative condition as they cut through different formations must be taken into account. There is little doubt on this point but that, in zones of similar original disturbance, those in the Fordham gneiss have suffered less extensively from disintegration than those cutting either the limestone or schist. Therefore, obscure as it may be, the preference is again in favor of Line P.

(4) If, as now appears, the present East river is displaced from its old channel by glacial drift, so that it is essentially an evicted stream, there may not be as pronounced a channel or as weak ground to cross at such point as at those where the old channel is still occupied. In such cases both of these lines are favorable.

(5) On the other hand, the crossing of Line P is almost a

mile nearer to the great Hudson gorge, to which doubtless this portion of the preglacial East river was tributary, and consequently its bed-rock channel, if it is the real preglacial channel, may be expected to be deeper and the accompanying disintegration (so far as it may be controlled by this factor) may be expected to reach lower than at points in similar surroundings farther up stream. It is impossible to say how much weight should be given to this objection. It does not seem to be of sufficient importance to fully offset the favorable features indicated in Items 1, 2 and 3.

On the basis of these studies Line P (the southerly one) near Manhattan bridge was chosen as the site of preliminary exploration promising the most favorable results. Later this was shifted a short distance without introducing any new conditions.

The accompanying map, Sheet 6, summarizes the results of this study of southern Manhattan. The formations and general arrangement of them is the same as on the original drawn before additional explorations were made, but the boundaries are corrected so as to be in keeping with the latest exploratory investigations.

SPECIAL EXPLORATION ZONES

Explorations by borings and other methods have been made at all questionable or uncertain points along the line. As was expected in the beginning five places have required elaborate exploration and some exceptional conditions have been proven. The original geological investigation based upon surface study as outlined in the foregoing pages served to locate these spots accurately.

These places or zones, now sufficiently well known to permit accurate statement of geologic conditions, are as follows:

(1) The Harlem River crossing at 167th street, where the aqueduct will cross from a ridge of Fordham gneiss beneath the Harlem river and where the whole thickness of Inwood limestone will be cut, reaching the ridge of Manhattan schist above the Speedway on Manhattan island.

(2) The Manhattanville cross valley, a low pass crossing the island at about 125th street (Manhattan street). The part explored extends from St. Nicholas to Morningside parks and crosses a zone with very low rock floor in the Manhattan schist.

(3) From Morningside to Central parks. The line crosses the strike of the formations at this point and cuts a longitudinal fault and anticlinal fold which tends to bring the Inwood limestone within surface influence.

(4) The Lower East Side zone. On Delancey street east of the Bowery, the line crosses the rock structure and at this point the whole series of crystalline formations appear. Besides complicated structure there is also exceptionally deep alteration or decay of bed-rock.

(5) The East River crossing—from the foot of Clinton street to Bridge street, Brooklyn.

Harlem River Crossing

Geologically the Harlem river between 155th and 200th streets has the same relation to local formations for the whole distance. It flows on the Inwood limestone bed which stands almost exactly on edge, while the east river-bluff is formed by the underlying Fordham gneiss, and the west, by a strong escarpment of Manhattan schist which extends southward throughout the whole of Manhattan forming the backbone of the island.

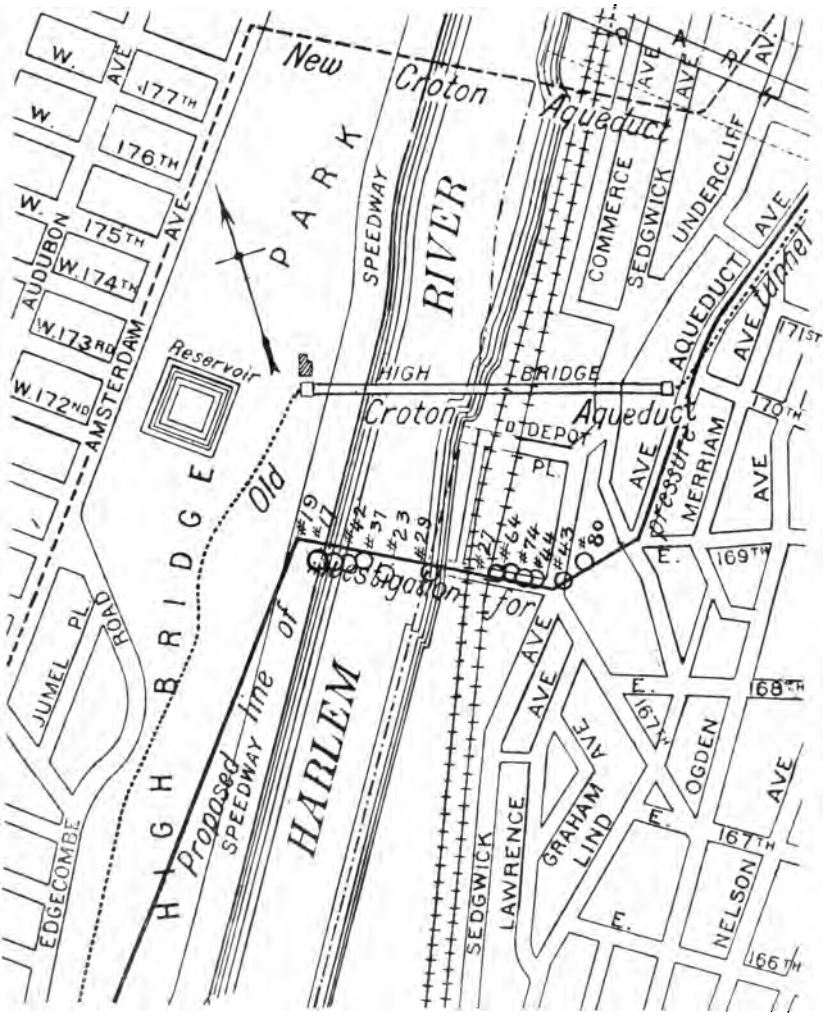
At the selected crossing a short distance below High bridge, near 167th street, the schist-limestone contact is in the river and appears to be a low weak spot (see detail of record). The limestone-gneiss contact, however, is in the flat east of the river bank, near Sedgwick avenue and seems to be more substantial. The structural detail and relations are shown on the accompanying profile and cross-section (Sheet 8).

It is observed by examination of the data secured by borings that the limestone formation at this point is exceptionally heavily impregnated with pegmatite dikes and stringers, and that interbedded schist layers are large and numerous.

The weakest spot found lies at the contact between schist and limestone where there is probably some longitudinal displacement.

A similar condition was found at the New Croton crossing 2,000 feet farther north. On the whole bad decay does not extend very deep—150 to 200 feet.

Several borings have been made and on them is based the only judgment possible of the actual structure and physical



Key map showing plan of exploratory borings at the Harlem River crossing, location of the New Croton aqueduct which crosses the Harlem in a pressure tunnel and the Old Croton aqueduct which crosses the river on High bridge.

condition of rock. In most cases the evidence is easily interpreted for these points. The most weakened spot, as well as the most difficult to interpret in all its detail, is the limestone-schist contact. It is judged that Hole 17 cut through this contact zone. This boring is located in the river 50 feet from the Speedway (west bank) on the proposed tunnel line which crosses a short distance south of High bridge. It is known as Hole 17/C38. Because of the somewhat unusual quality of material at this place, as indicated by the wash and core saved, and because of the suggestion it gives about the structure and condition of rock beneath the river, the record and interpretation notes are given.

0 feet to 13 feet—Water.

13 feet to 46 feet—Black river mud (mostly silt).

46 feet to 48 feet—Sand with decayed wood (peaty wood).

48 feet to 70 feet—Quartz and garnet sand rather clean (glacial).

46 feet to 70 feet—Lumps of peaty matter coming to the surface at intervals indicating occasional small layers of peat (glacial).

70 feet to 78 feet—Mixed sand (glacial).

92 feet—A core of Triassic contact shale (a drift boulder from the Palisade margin). At this point also a piece of Manhattan schist (boulder).

95 feet—Four pieces of diabase (Palisade trap) from another drift boulder.

96.5 feet—Five pieces of Inwood limestone (boulder) followed by a piece of quartzite and several mixed pebbles indicating glacial drift origin.

114 feet to 119 feet—A buff yellow sand with much pearly mica flakes. Effervesces with acid. This shows no foreign matter. It is chiefly residuary decayed rock in place and represents siliceous and micaceous limestone. It is decayed, very impure, Inwood limestone.

119 feet—Clay with pieces of flinty quartzite, probably from a small quartzose seam in the limestone.

120 feet to 126 feet—Light flaky yellow material. Much pearly mica with earthy matter. Effervesces in acid. Residuary from Inwood limestone.

128 feet—White and drab lumpy residuary matter (kaolin) and earthy substances. Effervesces. A more impure Inwood. Also shows several pieces of core of a porous, rotten limestone. Inwood.

129 feet to 134 feet—Reddish-brown lumps. Effervesces a very little. Mostly clay but still no foreign matter. Residuary material from a more siliceous bed. A few pieces of hard, impure limestone at 133 feet.

134 feet—Pieces of a porous quartz chlorite rock with little lime. Is a leached quartzose rock evidently a sandstone layer in the limestone. Rock belongs to the Inwood formation.

135 feet to 143 feet—Dark micaceous matter containing chiefly biotite, a pearly mica, and quartz. Rock is a decayed schist bed—the transition between Inwood limestone and Manhattan schist.

143 feet to 151 feet—Dark brown micaceous material. Biotite and quartz—chiefly. Rock is decayed schist (transition rock). At 146 feet encountered pieces of a pegmatite veinlet. All pieces except one are pegmatitic—the other one is calcareous sandstone, fallen into this lot from the 134-foot level.

151 feet to 160 feet—Chunks of pegmatite (a vein rock).

151 feet to 161 feet—The mica washings continue the same as at 143 feet to 151 feet. Rock is a transition schist with pegmatite stringers.

164 feet to 169 feet—Brownish yellow micaceous matter (loose). Mica, quartz, chlorite, lime. Effervesces.

164 feet to 173 feet—Many pieces of typical Manhattan schist. A fair amount of core for the conditions. Rock is not so badly decayed but is broken into small pieces. Rock is Manhattan schist of typical character.

SUMMARY

(1) The material is chiefly river silt down to 46 feet.

(2) Lighter glacial deposits 46 feet to 78 feet.

(3) Heavy bouldery drift 78 feet to 97 feet.

(4) Uncertain (insufficient data) 97 feet to 114 feet.

(5) Residuary micaceous decay products from Inwood limestone 114 feet to 135 feet.

(6) Decayed transition schist bed with some lime, but chiefly like the Manhattan schist 135 feet to 161 feet.

(7) More calcareous schist 161 feet to 164 feet.

(8) Typical Manhattan schist 164 feet to 173 feet.

INTERPRETATION

(1) Foreign matters, glacial and recent deposits, continue to a depth of between 97 and 114 feet.

(2) Rotten formations (residuary matter) in place begin at least as high as 114 feet. There is no foreign material below that point except grains that have fallen into the hole from above.

(3) More solid rock begins at 164 feet.

(4) The upper portion of the rotten rock (114 feet to 135 feet) is calcareous enough to belong to the Inwood limestone formation. The lower 9 feet (164 feet to 173 feet) is typical Manhattan schist. The intermediate ground 135 feet to 164 feet is transition variety.

(5) The drill has cut the contact between Inwood and Manhattan formation.

(6) If this identification of the badly decayed matter is correct, the contact at this point dips steeply eastward, i. e., it is overturned.

(7) Both types of rock are shown to be extensively decayed.

(8) The worst (deepest) decay zone probably lies a little farther east, and follows the dip of the micaceous limestone near the contact.

These conditions are indicated on the accompanying cross-section (see Sheet 8).

The conditions indicated by this one hole are consistent with those known for the New Croton Aqueduct tunnel 2,000 feet farther north where, according to the engineers' drawings, the formations also are overturned. Fifty feet of decayed rock is shown in this hole. The contact is undoubtedly decayed considerably to a depth of more than 200 feet below water-level.

Another boring put down to test conditions at still greater depth nearby explored the rock to –442.7 feet. Because of the information it gives about the deeper bed-rock, a summary of the record based upon examination of the material is given:

HOLE 42 (75 FEET FROM SPEEDWAY, 25 FEET EAST OF HOLE 17)

0 feet to –94.1 feet—River muds and various types of drift similar to Hole 17.

–94 feet to –96 feet—Iron cemented sand—both drift sand and local angular material.

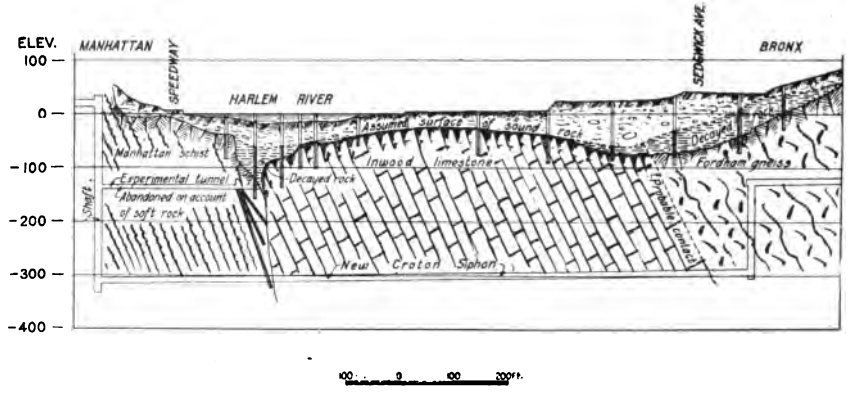
–98 feet to –127 feet—Micaceous clay—residuary decayed matter—with choppings of calcite, quartz, mica and chlorite representing weathered Inwood limestone.

–127 feet to –135 feet—Core—Inwood limestone (impure).

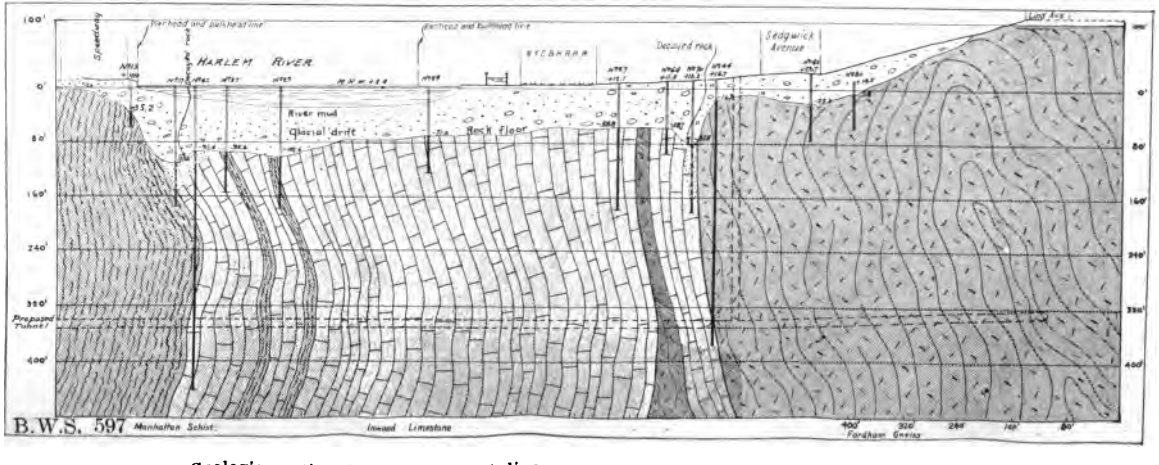
–135 feet to –149.5 feet—Pegmatite.

–149.5 feet to –197 feet—Inwood limestone—typical—standing almost vertical in upper portion but changing to about 45 degrees and farther down to 60 degrees. Good sound rock.

–197 feet to –241 feet—Manhattan schist—of typical sort—and in sound condition, but becoming somewhat more broken and altered near the bottom. Dip about 60 de-



Harlem River crossing. New Croton aqueduct.



Geologic section on the aqueduct line across the Harlem river about 167th street.

grees to 80 degrees and even more. Average probably 75 degrees to 80 degrees.

-241 feet to -295 feet—Manhattan schist—typical—dip variable but mostly above 70 degrees to vertical—some pegmatite—fractures are at high angle. Rock sound.

-295 feet to -302.5 feet—Pegmatite.

-302.5 feet to -442.7 feet—Inwood limestone—typical—good quality—dip 70 degrees to very flat—one piece not over 35 degrees but mostly obscure.

An interpretation summary is as follows:

0 feet to -94 feet—River muds and drift filling (glacial and recent).

-94 feet to -96 feet—Transition to residuary matter.

-96 feet to -127 feet—Residuary matter and badly decayed Inwood limestone.

-127 feet to -197 feet—Inwood limestone.

-197 feet to -302 feet—Manhattan schist.

-302 feet to -442.7 feet—Inwood limestone.

GEOLOGIC CROSS-SECTION

The accompanying cross-section (Sheet 8) embodies an interpretation of all the data secured in the Harlem river. It is now known that the limestone is overturned slightly at both contacts. The nature of these contacts makes it seem probable that there is very little of the limestone squeezed or cut out by movement. Therefore this crossing gives a fairly accurate measure of the thickness of the Inwood. This is approximately 750 feet. No section about New York City is more accurately determined.

Manhattanville Cross Valley

In northern Manhattan the schist ridge which forms the backbone of the island and has a relief of more than 100 feet, is cut across by a prominent valley that extends from the Hudson at 130th street eastward to the Harlem flats and East river.

This valley is nowhere more than 25 or 30 feet above the sea-level and is drift filled. Previous to the recent boring explorations of the Board of Water Supply its true depth to rock floor was unknown. The few borings recorded, however, indicated a depth of more than a hundred feet. One such boring at 129th street and Amsterdam avenue is reported as penetrating 109 feet from surface without touching rock. Another of similar results is located at 125th and Manhattan streets where a depth of 204 feet failed to touch rock.

Besides determining rock floor in the present case, it is important to determine rock structure and conditions. It appears from surface features that this cross valley probably follows a fault zone along which there has been weakening of the rock and consequent disintegration and decay. If this is so it would be advantageous to find the limits of it and determine what displacement effects were produced. It has been surmised by all students of local geology that such cross faults may lift the blocks on the south side of them, one of the chief indications being the fact that in spite of a strong southerly pitch in all the formations they do not rapidly disappear below sea-level.

The accompanying profile and explanatory section indicates the principal results of exploration (see Sheet 9). Badly crushed ground has been found in the holes near the north end of Morningside park but the rock, when found, is not very badly decayed. The rock floor is very low, almost 200 feet below sea-level at the lowest. It appears that if the drift were stripped off from this valley the Hudson and Long Island sound would unite across the Harlem flats and Manhattanville forming a channel and outlet much deeper than the present East River course.

The glacial drift of this valley is prevailingly fine modified drift some of which is probably stratified and fairly well assorted. This is more strikingly true of the southerly extension of this low ground southward along Morningside park. A very deep and prominent preglacial gulch came down from the gap between Morningside and Central parks.

It is not yet proven that the fault has really raised the Morningside block. At least if there is such displacement it is not of sufficient amount to bring up a different formation at

any point yet examined. It would be possible for the limestone to be brought up to the surface, but except for a few pieces of interbedded limestone no evidence has been secured. The occurrence of this, however, is thought to indicate proximity to the limestone contact.

GENERAL GEOLOGIC CONDITIONS ESTABLISHED

Fourteen borings have been made for the special purpose of determining exact conditions. On the data of these holes there are several features now established beyond question that were originally given only as probabilities. The most important of these may be enumerated as follows:

(1) A very deep cross valley is now proven between 123rd and 126th streets crossing Morningside Avenue East, and its profile can be plotted.

(2) A part of this ground is badly broken, as if belonging to a fault zone, but most of the floor thus far tested is not in bad condition, i. e., it is not very badly crushed or decayed.

(3) The drift cover in this cross valley is more than 200 feet deep over a distance of more than two blocks on the proposed line (from 123rd street to Manhattan street).

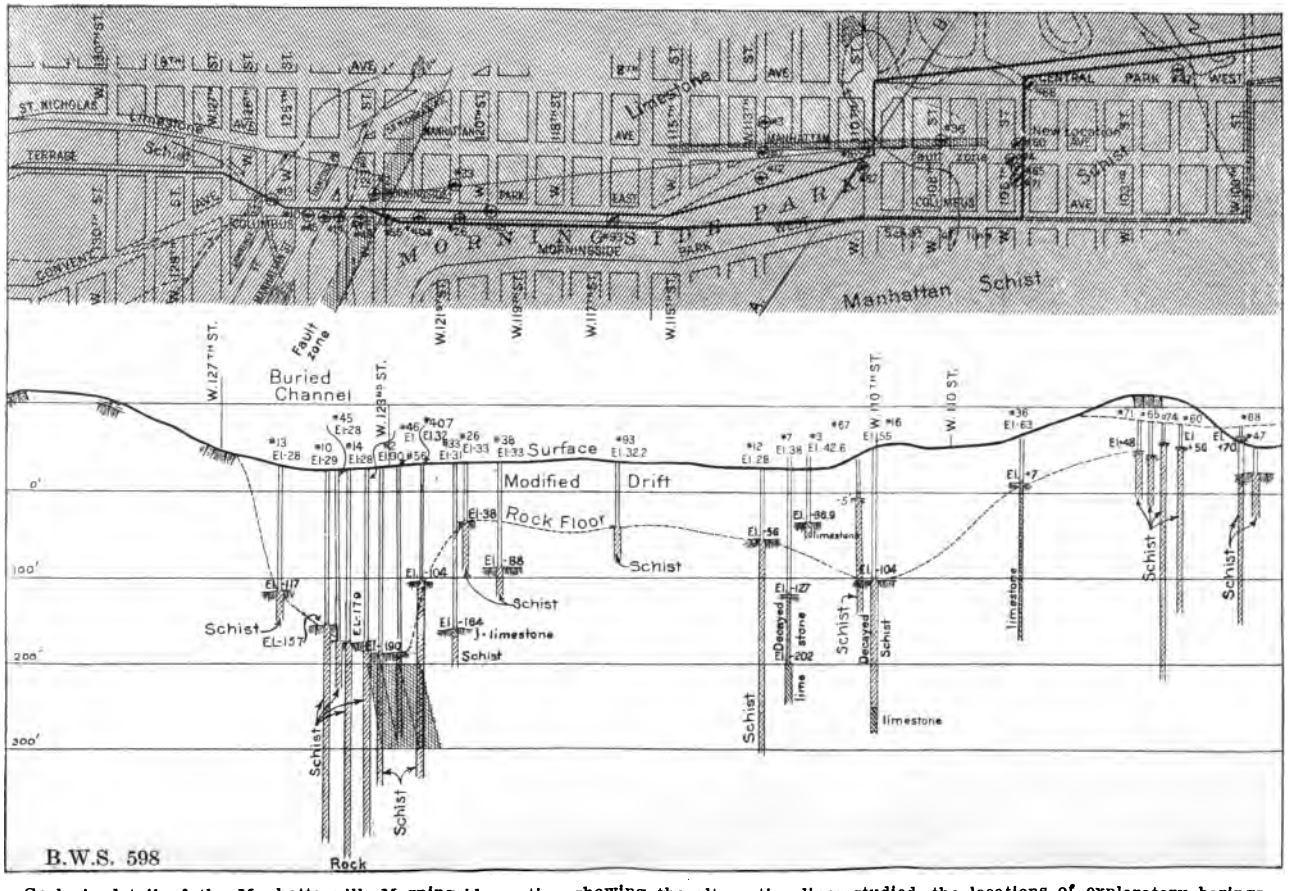
(4) The limestone contact lies more than 300 feet east of the proposed tunnel line at this Manhattan cross valley.

(5) At 121st street the limestone-schist contact stands very steep and is probably slightly overturned, so as to dip steeply to the east. This is indicated by the data of Hole 33, which lies to the east side of the line.

(6) The contact line approaches nearer to Morningside park in passing southward, touching the park between 110th and 113th streets, but the contact is probably not overturned in this southerly extension.

Morningside to Central Park

The contact between Inwood limestone and Manhattan schist follows nearly parallel with the Morningside Park boundary on the east side, but, because of its form, actually touches the park only at the south end between 110th and 113th streets. At the north end it lies off more than half a block to the east. The Manhattan schist forms an escarpment because of its more resistant character and this eastward facing cliff and slope



Geologic detail of the Manhattanville-Morningside section showing the alternative lines studied, the locations of exploratory borings, the two principal crush zones and longitudinal profiles.

forms Morningside park. St. Nicholas park, farther north, from 128th to 141st streets, has the same structural relations, and the same conditions prevail still further northward. In both cases the present escarpment stands back from 200 to 500 feet from the actual contact, and is covered heavily with drift.

As the formations all pitch southward and are closely folded, the higher formations gradually appear and at 110th street another parallel ridge of schist comes in above the limestone in the trough of the next syncline to the east. This forms the north end of Central park and from this point southward Manhattan schist is continuous. But between the Morningside belt of schist and the Central Park belt at 110th street lies an anticline of Inwood limestone also pitching southward, gradually passing beneath the schist, which encroaches upon it on both sides. A few blocks farther south it passes wholly beneath the schist, which from that point is continuous as the rock floor formation.

This anticlinal wedge together with its accompanying structures and rock condition was the subject of some detailed exploration.

The records of a few drill holes together with an interpretation of the data will serve the present purpose of illustrating the geologic features of this section.

HOLE 7, ON 113TH STREET, CORNER OF MANHATTAN AVENUE

Surface elevation, 38 feet.

Rock floor at depth of approximately 165 feet—Elevation −127 feet.

Material

0 feet to 85 feet—to Elevation −47 feet—modified drift.

85 feet to 165 feet—to Elevation −127 feet—sand with much more clay, part of which may be decayed rock.

165 feet to 240 feet—to Elevation −202 feet—disintegrated rock ledge. Some micaceous type believed to be the transitional facies of the schist-limestone contact.

242 feet to 280.71 feet—to Elevation –242.71 feet—Inwood, very coarse type of limestone. Poor core showing. Much broken.

HOLE 16, CORNER OF MANHATTAN AVENUE AND 110TH STREET

Surface elevation, 55 feet.

Rock floor at depth of 159 feet—Elevation –104 feet.

Material

0 feet to 44 feet—to Elevation 11 feet—filled ground and mixed material.

44 feet to 159 feet—to Elevation –104 feet—fine sands and silts interpreted as chiefly modified drift. Much of it very fine and the lower portion rather micaceous and angular throwing a little doubt on the exact line of demarcation between drift and residuary matter.

159 feet to 161 feet—to Elevation –106 feet—core of Manhattan schist.

171 feet to 186 feet—to Elevation –131 feet—decayed rock in place, some micaceous type, coming out as mud.

186 feet to 228 feet—to Elevation –173 feet—micaceous reddish mud with variable amounts of angular quartz grains. Certainly residuary decayed rock.

228 feet to 270 feet—to Elevation –215 feet—similar residuary matter less highly colored passing from reds into grays and coming out as soft material.

270 feet to 305 feet—to Elevation –250 feet—grayish micaceous and quartzose residuary matters. With much silvery mica and chloritic grains near the bottom.

305 feet to 335 feet—to Elevation –280 feet—Inwood limestone, core, ordinary type. No core recovered above this point except for two feet between 159 feet and 161 feet.

HOLE 36 AT 108TH STREET AND MANHATTAN AVENUE

Elevation of surface, 63 feet.

Rock floor (decayed) at depth of 55 feet—Elevation 8 feet.

Depth to solid core—248 feet—Elevation –185 feet.

Material

0 feet to 55 feet—Elevation 8 feet—modified drift (fine silts).

55 feet to 155 feet—to –92 feet—micaceous soft material with broken sand—decayed micaceous rock.

155 feet to 215 feet—to –152 feet—reddish mud of similar constituents. Is decayed rock colored by iron.

215 feet to 240 feet—to –177 feet—transition to more grayish and greenish soft matter.

240 feet to 245 feet—to –182 feet—greenish mica rock—a decayed chlorite, mica quartz, schist layer.

248.33 feet to 254.25 feet—from Elevation –185.35 to –191.25 feet—chloritic Inwood limestone.

A summary of these data gives:

0 feet to 55 feet—drift.

55 feet to 245 feet—decayed rock ledge.

248 feet to 254 feet—solid rock ledge (limestone).

HOLE 2 AT 123RD STREET, 100 FEET EAST OF MORNINGSIDE PARK EAST

Surface elevation, 30 feet.

Rock floor at depth of 220 feet—Elevation –190 feet.

Material

0 feet to 13 feet—to Elevation 17 feet—soil and mixed drift.

13 feet to 220 feet—to Elevation –190 feet—modified drift —mostly assorted sands and silts.

220 feet to 245 feet—to Elevation –215 feet—soft decayed schist.

245 feet to 355 feet—to Elevation −325 feet — Manhattan schist much broken—poor core recovery—worst material at about 225 feet to 240 feet and again near bottom. Formation evidently much shattered and considerably decayed.

HOLE 33 ON 121ST STREET, 300 FEET EAST OF MORNINGSIDE PARK EAST

Surface elevation, 31 feet.

Rock floor at depth of 195 feet—Elevation −164 feet.

Material

0 feet to 25 feet—soil and mixed drift.

25 feet to 195 feet—to Elevation −164 feet—drift, mostly modified drift—assorted sands and fine silts.

190 feet to 195 feet—coarser material—pebbles.

195 feet to 200 feet—to Elevation −169 feet—Inwood limestone, coarse limestone of usual type.

200 feet to 237 feet—to Elevation −206 feet — Manhattan schist.

Ordinary type and in good condition (for interpretation see later comments).

CONDITION OF THE LIMESTONE-SCHIST CONTACT ALONG THE MORNINGSIDE SECTION

The finding of Inwood limestone above the Manhattan schist in Hole 33 at 121st street east of Morningside and the fairly sound condition of both types raises the general question of the condition of contact zones as compared with fault zones.

There are three important facts to consider bearing on this case:

(1) The contact zones are commonly weaker than either formation alone.

(2) At this particular point an abnormal relationship is shown by the overturned strata (the limestone lying above).

(3) The fault zones are always weak and extensively decayed.

Because of the abnormal position of the limestone here, lying as it does overturned, a weaker more pervious rock upon a more substantial and less pervious one, it appears to be reasonable enough to find the limestone and schist fairly well preserved, under conditions where a vertical or a normal position would have encouraged decay because permitting a more ready circulation.

But fault or crush zones are more extensively decayed than the simple contact or transition zones. Therefore where an especially extensive decay is encountered it probably is to be associated with a crush zone due to fault movement rather than with any other structure.

A further inference seems allowable from the data of these holes. It is probable that these fault zones do not follow the contacts or bedding exactly but cut across at low angles, sometimes coinciding with the contact lines and sometimes falling wholly within the limestone or the schist.

GREAT DEPTH OF DECAY AT SOUTH END OF MORNINGSIDE PARK

The finding of approximately 150 feet of decayed rock in Hole 16 and of nearly 200 feet of similar type in Hole 36, all so rotten that the material came up as a mud, raises a very difficult question as to the conditions that make such extensive decay possible.

Hole 7 (113th street) shows extreme decay to Elevation −204 feet.

Hole 16 (110th street) shows similar condition to Elevation −250 feet.

Hole 36 (108th street) shows similar condition to Elevation −185 feet.

These three holes showing similar condition of very deep decay are located almost exactly in line. Nothing on either side of this line is in so poor condition.

Consideration of these conditions can not fail to raise certain questions of interpretation.

(1) It would appear that at least one of these borings (No. 7) is near the schist-limestone contact. May they all lie then in the weakened contact zone?

(2) It is true that at least one core (also from No. 7) shows a badly broken condition. May they all lie in a fault zone?

(3) There is no reasonable doubt but that the geologic structure at the south end of Morningside park is that of a pitching anticline carrying the limestone beneath the schist in its southward extension. May the excessive decay be due to this relation?

The evidence on these various possibilities is not complete enough to make a conclusion very reliable. But there are two or three factors that have a bearing and they unite reasonably well in supporting one view.

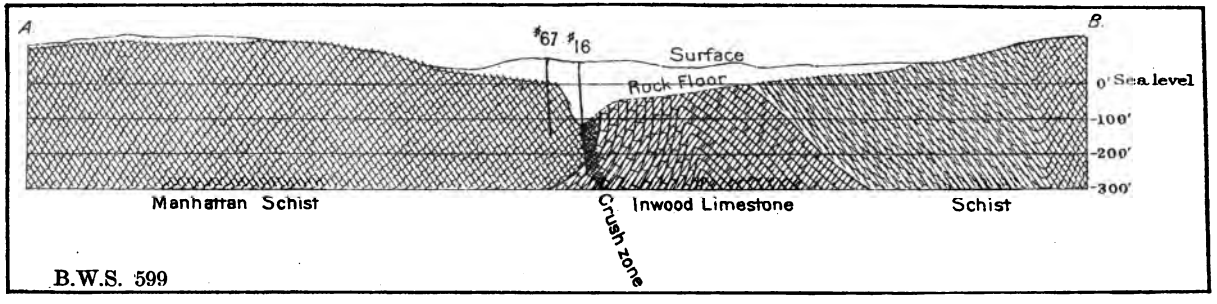
These factors are: (a) the exact alinement of these three holes, (b) the crushed core of Hole 7, (c) the overturned position of the formations 10 blocks farther north (Hole 33), together with the apparently normal position in Hole 16.

All of these points are consistent with the opinion that we have to do here with the crush zone of a fault, one that runs straight and one that follows not far from the contact of the schist and limestone at this point. And it is probable that the weakness follows the west margin or limb of the limestone anticline as it plunges beneath the schist. Such evidence as there is favors this view.

If that is true, then one may expect that the worst ground is not very wide, but that one probably can not go entirely around it. The best line would run south far enough to get above the limestone, and then cut across the weak zone, at right angles, wholly within the schist formation. It is certain that the ground improves southward.

Later borings are all confirmatory of the conclusion that the weakness is narrow and dies out rapidly southward as soon as the limestone passed well beneath the schist. No bad ground has yet been found on 106th street where the tunnel has been located.

The line was finally located four blocks farther south on 106th street, because of the conditions just described, and a number of borings were made between Columbus avenue and Central park for the purpose of determining whether or not the same weaknesses would be encountered there. All of the borings show Manhattan schist to as great depth as they were carried, and indicate rock of as good sound character as the



Geologic cross-section of the Line A-B near 110th street, from Morningside Heights to Central park, showing the anticlinal structure and location of the crush zone along which deep erosion and decay have been found.

SHEET 10

average on Manhattan island. With these results bearing out the opinion based on the geologic relations, no difficulty is anticipated at this point.

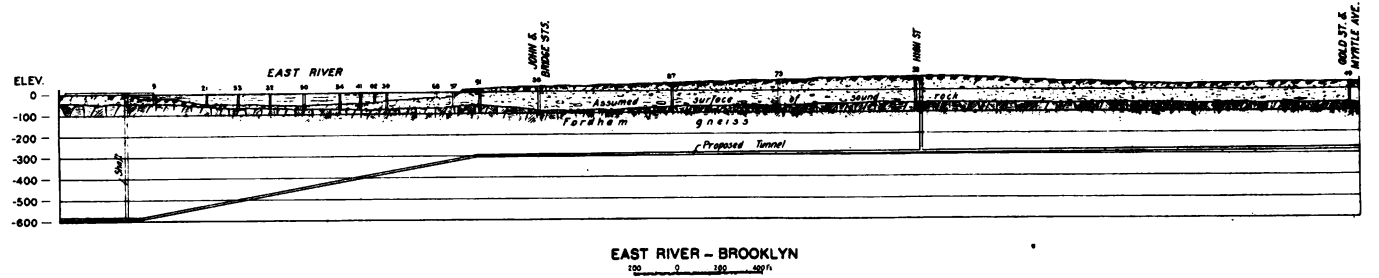
The East River Section

Preliminary studies of southern Manhattan and the East river as already given, led originally to the conclusion that the portion of the East river forming the great eastward bend from 32nd street to Brooklyn bridge probably has a simpler geologic structure than those portions farther north or south. It was long known that the structure at Blackwell's island is very complex and involves all of the local formations in close folding and considerable faulting. After studying all available data, there seems to be good reason to believe that the river leaves this belt when it bends to the eastward and that it is in this part a displaced stream. In that case the East river could be flowing upon a floor of gneiss of a most substantial sort.

Explorations are now complete on a line that crosses the river from Clinton street, Manhattan, to Bridge street, Brooklyn. All borings have found good sound rock at moderate depth and all are comparatively shallow holes. Their positions and rock types are tabulated below:

Number of Boring	Distances in Feet From Manhattan Pier Head Line	Approximate Interval in Feet	Elevation of Rock Floor Below Mean Sea-level in Feet	Type of Rock	Formation
9	...	...	−48	Grano-diorite	Fordham
21	225	225	−65	"	"
53	350	125	−72	"	"
32	525	175	−71	"	"
50	695	170	−76	"	"
34	860	165	−74	"	"
41	960	100	−81	"	"
39	1,070	110	−67	"	"
67	Brooklyn side near bulkhead	...	−75	Banded gneiss	"

The rock floor is thus very uniform as to contour across the East river at this point. No water course yet explored about Manhattan island has shown so simple conditions including as it does sound rock and shallow channel. The rock varies a good deal but is prevailingly a coarse grained grano-diorite.



SHEET 11

Profile of surface and rock floor as indicated by borings from the foot of Clinton street, Manhattan, to Gold street and Myrtle avenue, Brooklyn. The rock floor is chiefly some variety of the Ravenswood grano-diorite intrusive in the Fordham gneiss formation. It is one of the soundest rock types in New York City and the profile is more uniform than usual in any of the local formations. It is clear that the East river in this part of its course has no rock channel.

In places it is very garnetiferous and at others is banded or micaceous, but all belong to the Fordham formation as a general formational unit.

Borings in the East river made by the Public Service Commission both above and below this point found an occasional zone with excessive decay to more than a hundred feet without securing sound core. At this crossing, selected for the distribution conduit, the deepest point in the channel to sound rock floor is only 81 feet.

It is certain from these results and from others in adjacent ground that the East river in this part of its course does not occupy the original stream channel. It has been displaced (evicted) by glacial encroachment and has never been able to reoccupy the lost course. Therefore, instead of the river following a belt of limestone around this big bend, as was formerly supposed, it follows no rock floor structure at all but is in this part of its course wholly superimposed. The original valley lies farther to the west cutting through the midst of the lower east side where more complicated geologic structures again prevail.

Borings at intervals of 500 feet have now been made on the Brooklyn side of the East river to Gold street and Myrtle avenue. So far as developed there is no other formation than the Fordham and the associated grano-diorite within the area covered. The rock floor is remarkably uniform at an elevation of from –70 to –90 feet. The accompanying section shows the relations of rock floor to present drift surface (Sheet 11).

STRUCTURAL GEOLOGY OF THE LOWER EAST SIDE, DELANCEY AND CLINTON STREET SECTION

The proposed distributary conduit turns from the Bowery eastward on Delancey to Allen street, thence on Allen to Hester street, thence on Hester street to Clinton street and follows south on Clinton to the East river. This so-called Lower East Side section includes one of the most complicated geologic structures in New York City. The most complex portion extends from Chrystie street on the west side to Monroe street on the east. Between these two points all of the crystalline rock formations form a series of parallel beds that are folded together so closely that they stand practically on edge.

This general fact and the approximate location of the several beds have been proven for some time. But the more exact structure, with the depths to which the beds go before bending upward again, and the distances through each one are only approximately determined by the exploratory borings. Additional obscurities arise from the fact that the beds are also faulted, the dips of the fault planes are not fully determined and the amount of displacement is unknown. The difficulty of forming a good estimate of such points is greatly increased by the fact that no rock of any kind is to be seen at the surface. Judgment is based wholly on borings.

There are other important questions touching this zone, such as: (1) the depth of serious decay, (2) location and width of these decay belts, (3) general physical condition of the rock at certain levels, (4) length of tunnel that will cut each formation, (5) best depth for safe construction.

The accompanying geologic cross-section (Sheets 12 to 15) embodies an opinion of the structural relations of the different formations. It is offered as an interpretation of borings to date, and its more direct use is as a working basis and guide in conducting explorations. The western half of the section may be accepted as more accurate in minor detail than the eastern.

To simplify the section it is drawn on a line crossing this zone more directly than the conduit as laid out, i. e., through Holes 28 and 5 and the borings are projected along the strike of the formation to the section line. All the data therefore are used and the structure is not distorted, but the distances through each bed would be greater on the conduit line because it runs more diagonally across the formations.

BORINGS

Many borings have been made on this section between the Bowery and the East river. No other portion of the line has required so elaborate exploratory investigation to satisfy the demand for reliable data.

The drift cover lies very thick on a variable rock floor. The maximum thickness indicated is 240 feet by Boring 219 at the corner of Clinton and Madison streets. It is largely modified drift such as sand and gravel; but there is enough heavy

bouldery ground to give much trouble in sinking to bed-rock with the drill.

Samples obtained by drilling have proven to be more variable and the data all together are more difficult to interpret than at any other point. Many of the borings indicate considerable rock decay to depths of 500 or even, in rare cases, to 600 feet. In a large number there is evidence of crushing and movement such as is commonly developed by faulting. In a large number there is abundant evidence of alternating layers of limestone and gneiss together. In some of the holes more than one limestone bed is penetrated. There is furthermore a great variation in angle of dip in different places—sometimes even in the same hole, but the average dip is certainly greater than 45 degrees.

Four important types of rock occur in the Lower East Side section. Manhattan schist lies beneath the Bowery at Delancey street and extends one block eastward to Chrystie street. Inwood limestone then forms a belt a block and a half wide between the schist and a strip of Fordham gneiss, which is only about a block and a half wide also. A strong belt of limestone lies immediately to the east, and this is followed by a remarkable series of interbedded layers of limestone and gneiss belonging to the Fordham gneiss series. This continues as far as Monroe and Clinton streets, where there is a decided change and thence southward to the East river and across it and into Brooklyn the prevailing type of rock is Ravenswood granodiorite.

These four formations have the usual structural relation. The schist, limestone and gneiss are clearly folded so that their eroded edges form parallel belts striking about North 30° East. The Ravenswood grano-diorite is intrusive in the Fordham gneiss.

FAULT ZONES

Fault movements have disturbed the strata also and those of later time are not rehealed, but still show crush zone effects. These are the weakest places in the rock floor and are the places where rock decay extends to great depth. All of the evidence thus far secured leads to the conclusion that these zones of weak rock are all very narrow, that they strike parallel to the strata, and that they become gradually but per-

manently more substantial with increase of depth. Doubtless there is a tendency for decay effects to follow some of the weaker beds of rock across which the faults cut, and in this way one finds some decay of rock in undisturbed material at surprising depths. But this effect is undoubtedly very local and always closely associated with adjacent crush zones which have been the real sources of the attack.

It is clear that the limestone belt at Forsyth street is too narrow to accommodate the whole normal thickness of Inwood, 750 feet. It is therefore certain that a part of it has been cut out by faulting or it has been squeezed out in the folding process or else it is not the same formation at all. The condition of the rock at the contact between limestone and gneiss shown in Boring 223 supports the view that there is faulting along this contact.

INTERBEDDED LIMESTONES IN THE FORDHAM SERIES

Numerous narrow limestones are interbedded with the quartzitic and schistose layers of the Fordham gneiss series. Nowhere are they more abundant or more persistent than in the Lower East Side section. All of the borings within the gneiss area of this district except those near the East river have shown some limestone.

Individual beds vary greatly in thickness. Because of the steepness of dip, and the obscurity of this factor in many cases, it is not possible to compute them closely. It is probable that most of them are not over 5 to 10 feet thick, although rarely a thickness of 25 or 30 feet may be represented. It is certain also that a considerable number of separate beds are penetrated. All attempts to correlate the limestone cores from different adjacent holes have so far met with little success. No doubt some of those cut at great depth in one hole correspond to others cut higher in an adjacent hole. But the differences in thickness are notable even in the best cases, and it is evident that little dependence can be put upon uniformity of thickness as a factor in correlation. The foldings and crumplings and shearing have probably affected the limestone members of the series more than any others. Limestones in comparatively thin beds are, under such conditions, especially liable to excessive thinning and thickening through recrystalliz-

ation and rock flowage. It is therefore not at all likely that any single bed at present preserves much uniformity of thickness. In some places they are pinched out entirely while in others they may attain a thickness much greater than the original. It is possible also that some of them are repeated by folding. Whether or not this is true in the Lower East Side section has not yet been determined. On the whole there is no direct evidence of repetition in this way. After making allowance for all possible duplication there is still a surprisingly large number of limestone interbeds represented—probably 10—a larger number in succession than is known anywhere else in southeastern New York (see Sheets 12 to 15).

In petrographic character these so-called limestones are all essentially very coarsely crystalline dolomitic marbles or silicated dolomites of still more complex constitution. Occasionally a very pure carbonate rock is represented that corresponds in appearance very closely indeed to the best grades of the Inwood, but there is no doubt whatever of the true interbedded relation of these limestones. Their similarity of appearance to the Inwood in certain facies is so great that from the petrographic evidence alone one could not differentiate them. Their field relation, however, is unmistakable and they belong unquestionably to an entirely different geologic formation from the Inwood—a much older one, in fact the oldest known formation in southeastern New York—equivalent to the Grenville series of the Adirondacks and Canada. The silicated facies contains many of the common products of metamorphic processes. Recrystallization has produced micaceous minerals such as phlogopite and chlorite in abundance. Original and secondary quartz is plentiful. Serpentine, tremolite, diopside, actinolite, occasionally chondrodite, and rarely metallic ores are found. In many cases the limestone passes by transition gradually into a more and more siliceous facies until the rock is simply a siliceous Fordham gneiss with quartz, mica and feldspar as the essential constituents. There is seldom a sharp break between the two types. Many pieces of apparently simple gneiss will show effervescence or a carbonate constituent with acid.

The siliceous beds of the gneiss series proper immediately associated with the limestone layers are also more siliceous or

more micaceous than the average Fordham. They are essentially micaceous quartzites and mica schists and the rock generally lacks the strong black and white banding that characterizes the common or typical Fordham gneiss of other localities. It is this facies of the gneiss which most closely resembles certain varieties of the Manhattan schist, and when the rock is much decayed or badly broken or is ground to pieces by the drill the confusion is still greater. The micaceous variety may readily be mistaken for Manhattan schist and the accompanying limestone may equally be mistaken for Inwood.

The occurrence of interbedded limestones in the Fordham series is probably more common than was formerly believed. They are not very often seen on the surface in areas of gneiss. Possibly this is largely due to differential weathering and erosion which together tend to obscure those portions of outcrops where such beds may occur. But the type is well known. It is certain that there are interbedded limestones with the gneisses in the Highlands. There are similar occurrences in the typical Fordham gneisses of The Bronx, New York City. The vicinity of Jerome Park reservoir is the best locality in all southeastern New York to see this interbedded development. The best exposures are at the following places:

(1) In the margin of Jerome Park reservoir at 205th street.

(2) East side of Villa avenue north of Bedford Park boulevard.

(3) East of the Concourse between 198th and 199th streets.

(4) South side of 196th street both east and west of the Concourse.

These occurrences in the vicinity of Jerome Park reservoir are essentially the same as those disclosed by the borings of the lower east side. In spite of its thick drift cover—50 to 200 feet—there are more limestone interbeds known there than in any other area of similar size in the region. It is entirely possible that a thorough exploration in certain other belts might reveal an equally elaborate development elsewhere.

The finding of interbedded limestones as a prominent element in certain facies of the gneiss series and their association with typical siliceous gneiss layers with transitional relation

emphasizes still more the strictly sedimentary origin of at least some portions of the Fordham series. Other observations lead to the conclusion that they are the oldest members of the series and that the igneous associates, of which there are many, are all younger intrusives.

One of these later intrusives is the Ravenswood granodiorite which cuts into the eastern margin of the lower east side, forms the floor of the present East River channel at the point of aqueduct crossing and continues as far as explorations have been carried into Brooklyn.

All of these factors and as much of the detail as seems useful are included in the accompanying cross-section (Sheets 12 to 15).

CHARACTER OF THE DRIFT COVER OF THE LOWER EAST SIDE SECTION AND ESPECIALLY THE DELANCEY STREET SHAFT SITE

Boring 225 on Delancey street between Eldridge and Allen streets is a proposed shaft site. Many other borings have been made in the vicinity—on Delancey, Grand, Hester, and Clinton streets—most of which also have given reliable evidence as to the character of the drift above the rock floor.

The following is a tabulation of the materials representing the drift cover at Boring 225.

Elevation of surface—about 40 feet.

Depth of drift cover above rock floor—about 114 feet.

Water-table about 30 feet below the surface.

Detail of materials:

0 feet to 10 feet—medium sand rather uniform.

10 feet to 20 feet—coarse sand of mixed character not so well assorted.

20 feet to 30 feet—coarse sand and fine gravel—mixed character but washed clean.

30 feet to 40 feet—same.

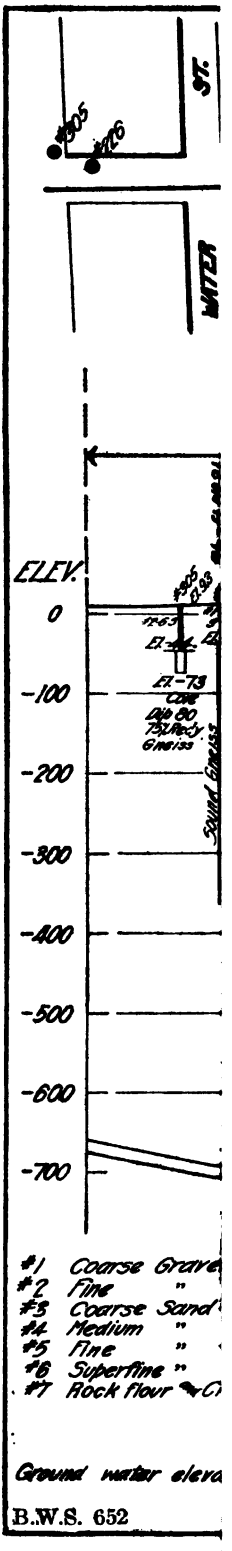
40 feet to 50 feet—medium sand—clean.

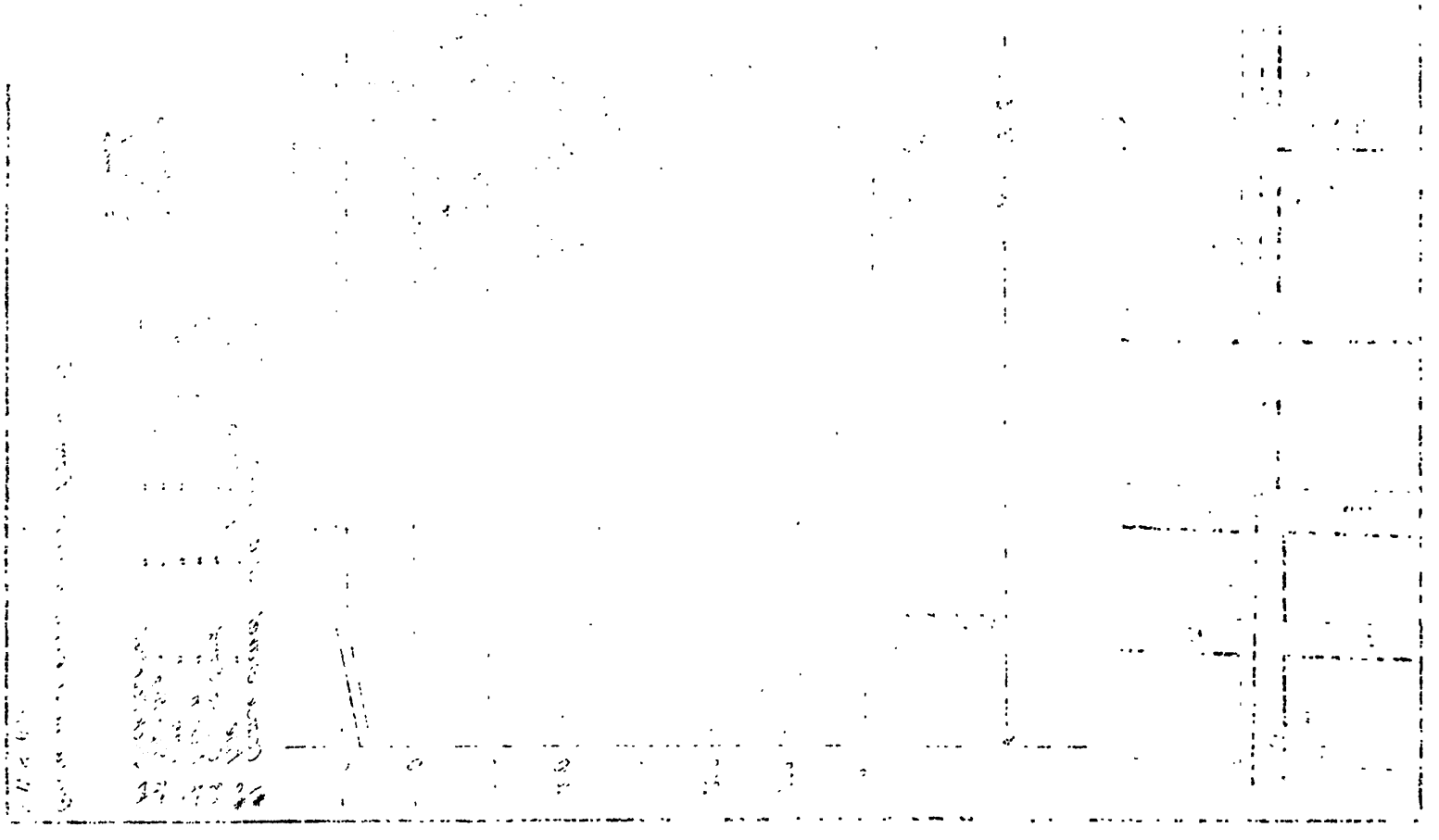
50 feet to 60 feet—fine sand—much finer than above.

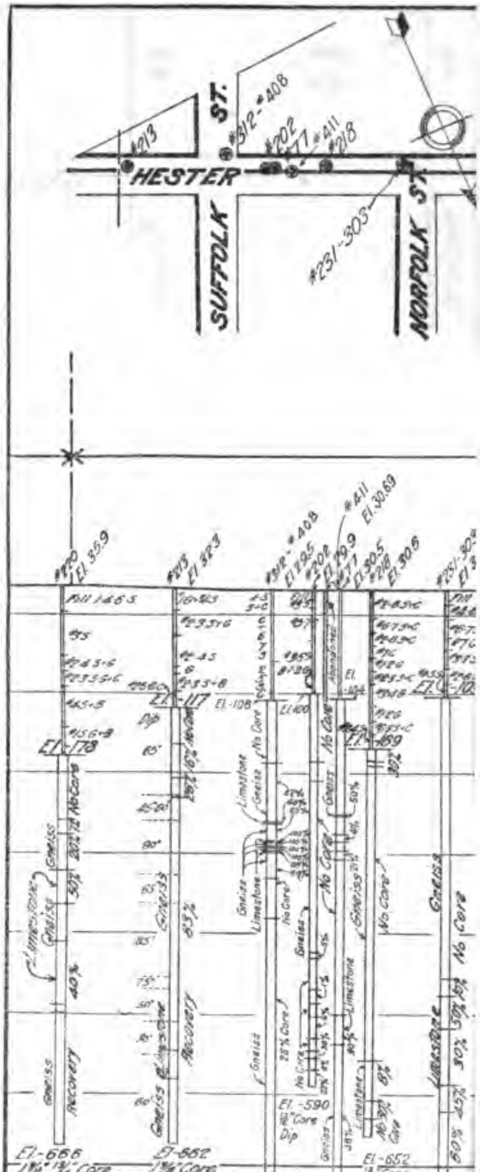
60 feet to 70 feet—very fine sand or silt.

70 feet to 80 feet—fine sand like that from 50 feet to 60 feet, but not so fine as the last number.

80 feet to 92 feet—very fine sand like 60 feet to 70 feet—packs down well—reddish color.


ST.
WATER
#105
#106
ELEV.
0
-100
-200
-300
-400
-500
-600
-700
Sound Gneiss
#1 Coarse Grave
#2 Fine "
#3 Coarse Sand
#4 Medium "
#5 Fine "
#6 Superfine "
#7 Rock flour
Ground water elev
B.W.S. 652

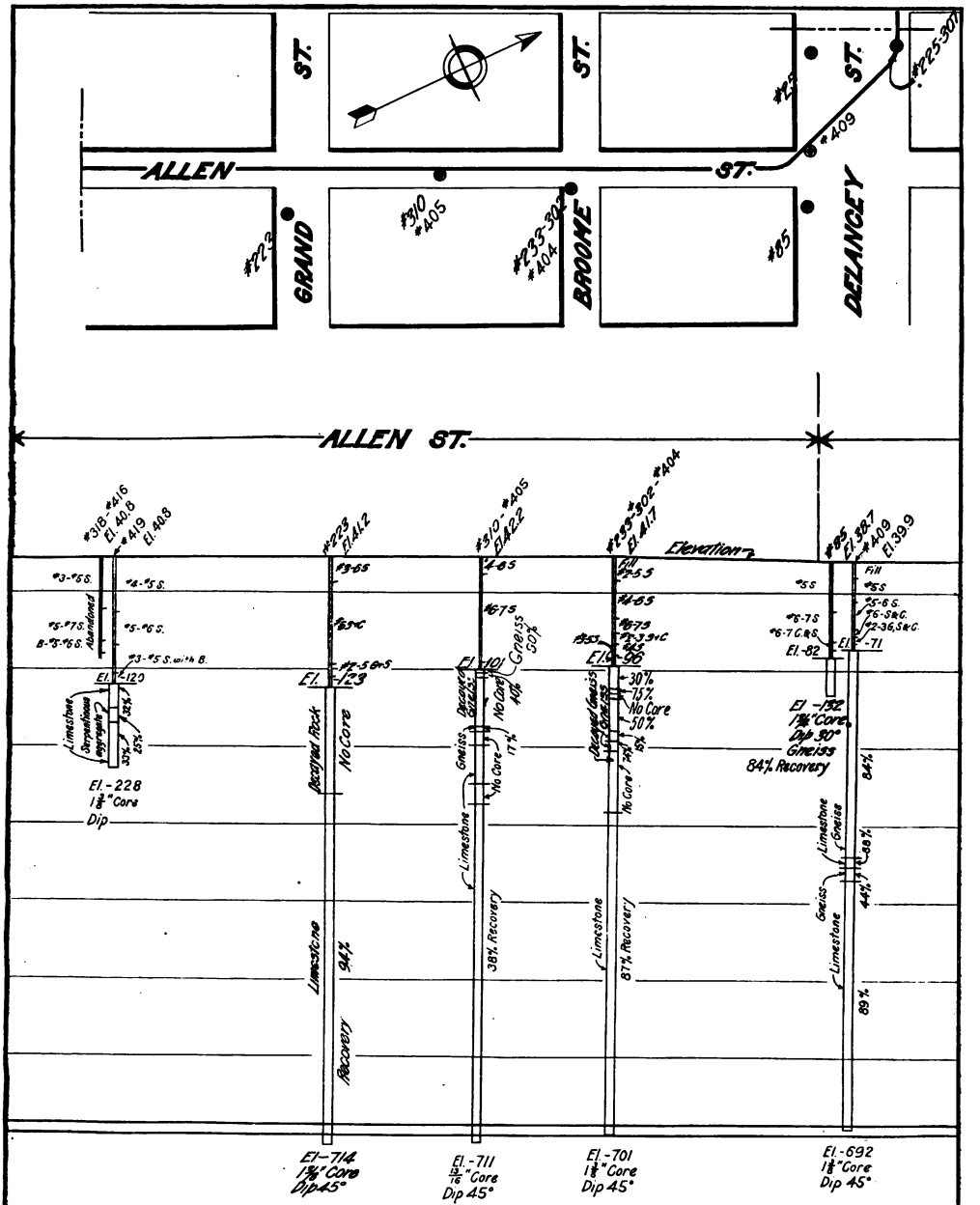



HESTER
SUFFOLK ST.
NORFOLK ST.
#213
#312-#408
#202
#77
#411
#218
#231-303
#213 El. 35.9
#213 El. 32.3
#312-#408 El. 29.5
#202 El. 29.9
#411 El. 30.69
#77 El. 30.5
#218 El. 30.6
El. -178
El. -117
El. -108
El. -100
El. -104
El. -189
No Core
Gneiss
Limestone
Recovery
Abandoned
El. -590
Dip
El.-666
1 13/16" 13/16" Core
Dip 60°
El.-662
1 3/16" Core
El.-700
1 13/16" & 13/16" Core
Dip
217' to 347' — 45°
347' to 570' — 60°
570' to 729' — 90° to 80°
El.-700
1 13/16" & 13/16"
Dip 50°-60°
El.-652
13/16" Core
Dip 50°-70°
El.-700
3/4" Core
Dip 45°-

#1	Coarse Gravel	size	above		
#2	Fine "	"	between	5	and
#3	Coarse Sand	"	"	1	"
#4	Medium "	"	"	.5	"
#5	Fine "	"	"	.25	"
#6	Superfine "	"	"	.10	"
#7	Rock Flour and Clay	"	"	.05	"

Ground water elevation varies from 0 to

B.W.S. 679



#1	Coarse Gravel	size above		5 mm.
#2	Fine "	" between	5 mm.	1 mm.
#3	Coarse Sand	" "	1 "	.5 mm.
#4	Medium "	" "	.5 "	.25 mm.
#5	Fine "	" "	.25 "	.10 mm.
#6	Superfine "	" "	.10 "	.05 mm.
#7	Rock flour & Clay	" "	.05 "	.01 mm.

B Boulders
C Clay
S Sand
G Gravel

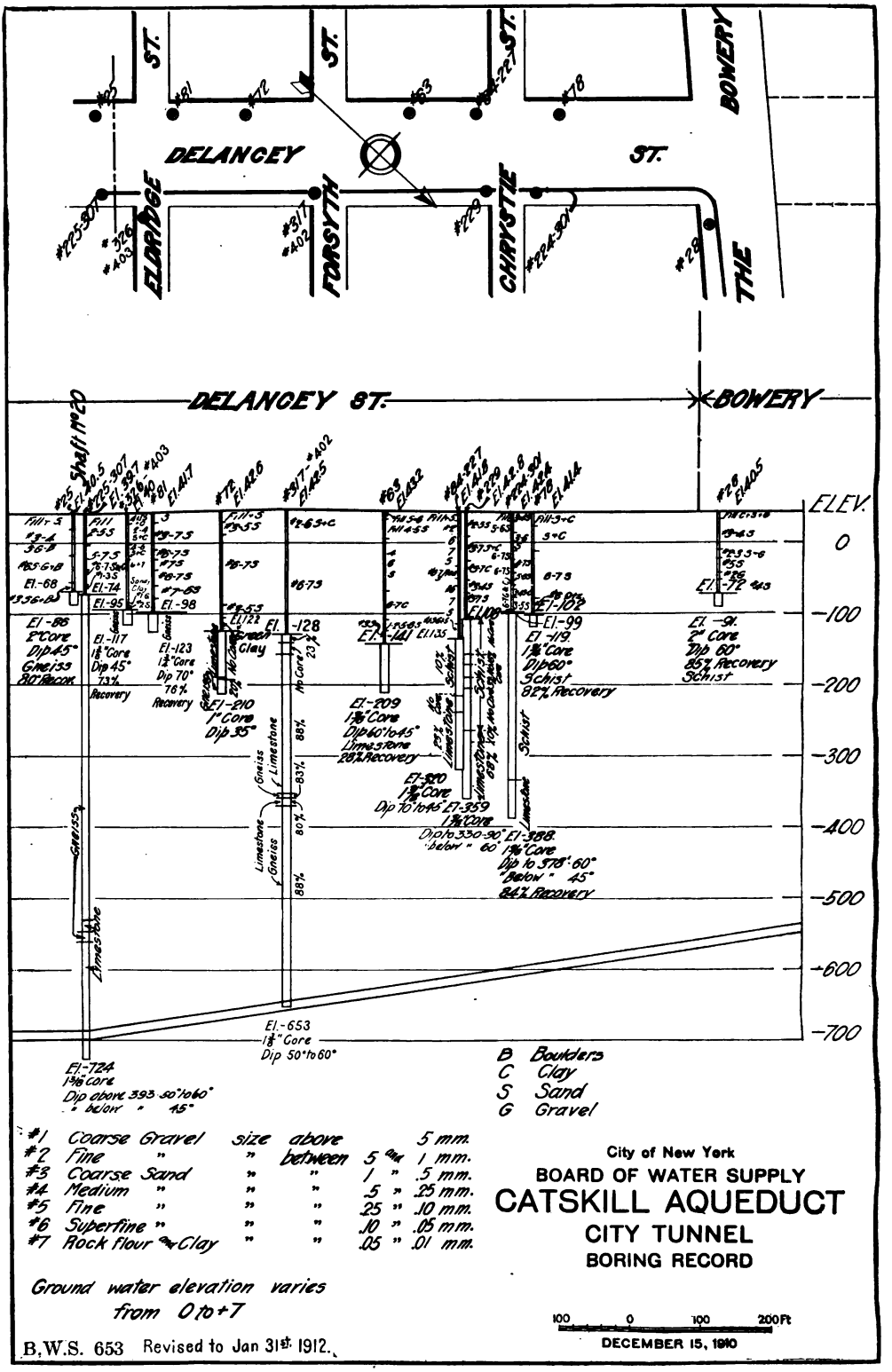
B.W.S. 678 Ground water elevation varies from 0 to +7

City of New York
BOARD OF WATER SUPPLY
CATSKILL AQUEDUCT
CITY TUNNEL
BORING RECORD

100 0 100 200 Ft

DECEMBER 15, 1910

Revised to Jan 31st 1912


DELANCEY ST.
BOWERY
ELDRIDGE ST.
FORSYTH ST.
CHRYSTIE ST.
DELANCEY ST.
BOWERY
THE
ELEV.
0
-100
-200
-300
-400
-500
-600
-700
Shaft No 2
El.-724
1⅜ Core
Dip above 393 30°to60°
" below " 45°
El.-653
1⅜" Core
Dip 50°to60°
B Boulders
C Clay
S Sand
G Gravel
#1 Coarse Gravel size above 5 mm.
#2 Fine " " between 5 " 1 mm.
#3 Coarse Sand " " 1 " .5 mm.
#4 Medium " " " .5 " .25 mm.
#5 Fine " " " .25 " .10 mm.
#6 Superfine " " " .10 " .05 mm.
#7 Rock flour & Clay " " .05 " .01 mm.
Ground water elevation varies from 0 to +7
B.W.S. 653 Revised to Jan 31st 1912.
City of New York
BOARD OF WATER SUPPLY
CATSKILL AQUEDUCT
CITY TUNNEL
BORING RECORD
100 0 100 200 Ft
DECEMBER 15, 1910

92 feet to 104 feet—very fine sand—nicely assorted and uniform—dark bluish gray color.
112 feet to 114 feet—coarse sand and fine gravel—mixed character and very variable.

Comment

Nearly all of these materials are assorted sands and gravels and doubtless represent strongly stratified drift deposits. An analysis of the record of the hole shows that the coarser sands, some of which carry an abundance of fine gravels occupy the upper 40 feet and a thin layer of a few feet near the bottom. Very fine sand (silt) is the prevailing quality from a depth of 50 feet to 104 feet.

Fine sands of so uniform grade mean that at this depth they are unusually well assorted and were probably laid down in standing water or rather quiet water into which these materials were carried as a silt. There is every reason to believe that they are horizontally stratified and that similar character of deposits prevails throughout the vicinity.

Some of the samples have the appearance of "quicksand." There are doubtless some portions of this zone between 50 and 104 feet that will behave like a quicksand in working.

The general freedom from fine mud and the very clean character of all of the samples indicates that there is practically no "till" or boulder clay and that the whole drift cover is very pervious to water. It is certain that these sands are saturated with water, that they hold great quantities of it wherever the assorted drift extends and that there is easy underground circulation which is no doubt more free laterally than vertically.

Other borings in this district, although they vary considerably among themselves, show similar character of materials. They support the conclusion that porous stratified fine and coarse sands and gravel underlie all of that portion of the lower east side which has very deep rock floor.

Application

The Delancey Street shaft will penetrate very troublesome ground throughout most of the 114 feet of stratified drift that covers the rock floor.

The lower 50 feet may be expected to exhibit quicksand behavior.

The whole shaft below the water-table (30 feet) to bed-rock (114 feet) will be exceedingly wet. There is no doubt about the abundance of water. This together with the caving tendencies of such fine-grained water-logged sands will make it necessary to adopt special measures for handling the ground.

It does not appear that any other site in the immediate vicinity would give materially different conditions.

GEOLOGICAL CONDITIONS AT THE PROPOSED SILVER LAKE RESERVOIR

Silver lake in the northern part of Staten Island has an elevation of about 200 feet above the sea. It occupies the upper portion of a small valley opening southward, and is separated on the north by a low divide from another depression which opens westward. It is proposed to utilize both depressions as a reservoir site, keeping the two basins separate by a dike. Catskill water will be led to this point from the terminal shaft of the distribution tunnel in Brooklyn through steel pipes and a short approach tunnel.

Questions

Questions of immediate consequence bear chiefly upon the geological character of the locality.

(a) What are the geologic formations?

(b) Are the basins essentially impervious or will they require lining?

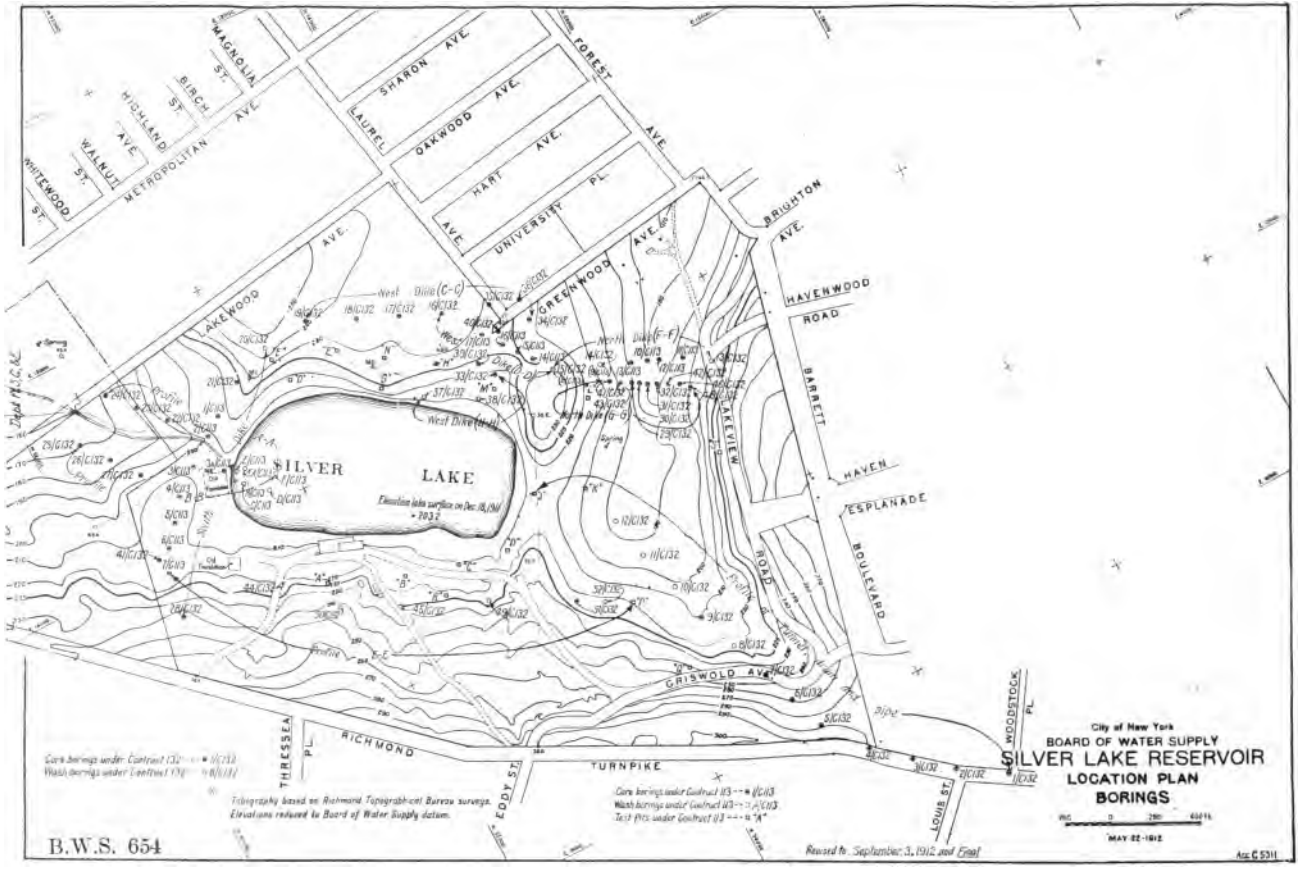
(c) Is there good material for dike construction on the ground?

Geological Formations

The rock floor is entirely covered with glacial drift in the immediate vicinity of the Silver Lake site. But on all sides at no very great distance the character of bed-rock is known.

There are only two formations: (a) The Staten Island serpentine, and (b) Glacial drift.

The Staten Island serpentine occupies almost the whole of the elevated portion of Staten Island. Within the area in which it is known to occur, no other rock formation has ever


SILVER LAKE
LAKE
City of New York
BOARD OF WATER SUPPLY
SILVER LAKE RESERVOIR
LOCATION PLAN
BORINGS
B.W.S. 654
MAY 22 - 1912
Revised to September 3, 1912 and Final
Acc. C 5311
Core borings under Contract 132 --- ● 11(C132)
Wash borings under Contract 132 --- ○ 11(C132)
Topography based on Richmond Topographical Bureau surveys.
Elevations reduced to Board of Water Supply datum.
Core borings under Contract 113 --- ● 11(C113)
Wash borings under Contract 113 --- ○ 11(C113)
Test Pits under Contract 113 --- ▭ "A"
MAGNOLIA AVE.
BIRCH ST.
HIGHLAND AVE.
WALNUT ST.
WHITEWOOD ST.
METROPOLITAN AVE.
LAUREL AVE.
SHARON AVE.
OAKWOOD AVE.
HART AVE.
UNIVERSITY PL.
FOREST AVE.
BRIGHTON AVE.
HAVENWOOD ROAD
BARRETT HAVEN
ESPLANADE BOULEVARD
LAKEWOOD AVE.
GREENWOOD AVE.
LAKEVIEW ROAD
GRISWOLD AVE.
WOODSTOCK PL.
LOUIS ST.
LODY ST.
THRESSEA PL.
RICHMOND TURNPIKE

SHEET 16

been found. This formation is unlike anything yet encountered on the Catskill Aqueduct work. The serpentine is more closely related to the old crystalline schists and gneisses, known as Manhattan schist and Fordham gneiss, than to any others, but it is an independent unit. This rock was originally an igneous intrusive of very basic composition (probably a pyroxenite) which pushed or fused its way into the old crystalline schists and finally cooled as a great mass or "boss." It is thus of the same origin and form as the granite masses encountered at several places in the Highlands, or the granodiorite of the East River district.

But this old basic rock has yielded much more readily to alteration and modification than the more acid granite types and as a result common greenish hydrous magnesian silicates as secondary minerals are developed in such abundance that the whole rock is called "serpentine." In most cases not a single original mineral constituent can be found, but traces of original structure can be seen microscopically, showing without doubt that this is the origin of the rock. The serpentine mass extends downward indefinitely. It is essentially a massive rock—lacking all banding or bedding or marked foliation. It is much jointed—very irregularly, but the joints are fairly tight.

The glacial drift cover is everywhere on the surface a heavy bouldery till. It varies greatly in thickness from only four to five feet to perhaps 100 feet. No one can tell from surface appearance just how thick it is, but exploratory borings show that depressions are much more heavily covered than the hillsides. It is nearly all of the mixed drift ("till") type—boulders, gravel, sand, and clay all mixed together.

Imperviousness of the Basins

The existence of serpentine as the bed-rock formation has been proven at all points as was to be expected. No unlooked for or unusual conditions or structures have been discovered or indicated in this rock. It is essentially massive and much jointed, but the crevices do not stand open conspicuously. These crevices form a complex network of possible channels for ground-water, but the amount that the rock as a whole can carry and the extent to which circulation is encouraged

by this condition is certainly comparatively small. There is no such thing as interstitial porosity like in a sandstone, or bedding structure like in sedimentary rock. Such water as may find its way out of the basin through the surrounding and underlying bed-rock must follow the most tortuous courses, its movement must be extremely slow, and its effect on the rock itself is practically nil.

Bed-rock of the type of the Staten Island serpentine may therefore be regarded as practically impervious. This rock certainly forms the enclosing wall on the east side and north side complete and for most of the distance on the west side. No better bed-rock exists in southern New York for such purpose.

But probably at no point will the waters of this reservoir come in direct contact with the bed-rock. Everywhere there is an overlying mantle of glacial drift, soil, and lake mud, which has a more direct bearing on the question of efficiency in holding water than the bed-rock itself. This is because the drift is deep at the very places where the natural tendency of water flow is greatest, i. e., in the valley bottoms toward the south and toward the west; and, if pervious enough, it would be possible to lose all of the water of both basins through this material, no matter how impervious the bed-rock may be or how perfect a dike were built on top of the drift.

The most essential thing then is the character of the drift at these critical points—the places to be occupied by the South dike, the North dike, and the West dike. These conditions have been discussed in detail in special reports. It is fair to say at this point that there are yet at each point some minor explorations to be made. But data have been accumulated of a decidedly reliable nature bearing on this question, and, assuming that the additional exploratory work reveals similar conditions, it seems to me that there will be no doubt about the water-holding efficiency of the whole reservoir. The type of drift mantle is prevailingly a heavy bouldery or stony till with only here and there patches or lenses of pervious sands and gravels of very limited extent which appear to be so interlocked with the impervious material that the whole mass, when treated on a large scale, becomes essentially as impervious as a "till." This result is decidedly encouraged by the fact that there is almost everywhere a layer of dense impervious "till" on top

so that the tendency to start circulation in the drift is checked at its beginning. Furthermore, where the 3 dikes are to be placed, which cover at the same time the only critical spots, there is in each case a wide stretch of ground, both in front of and behind the dike, in which the same general type of drift occurs, adding materially to the obstruction of water circulation.

It is as tight and impervious as the average " hard-pan " or till of southern New York. There is every reason to regard this material as an eminently satisfactory natural lining of the basins as they now stand. It is also suitable for use as dike material. The fact that Silver lake holds water permanently in all kinds of seasons is sufficient proof of the efficiency of this natural material. The basins will not require lining.

Material for Dike Construction

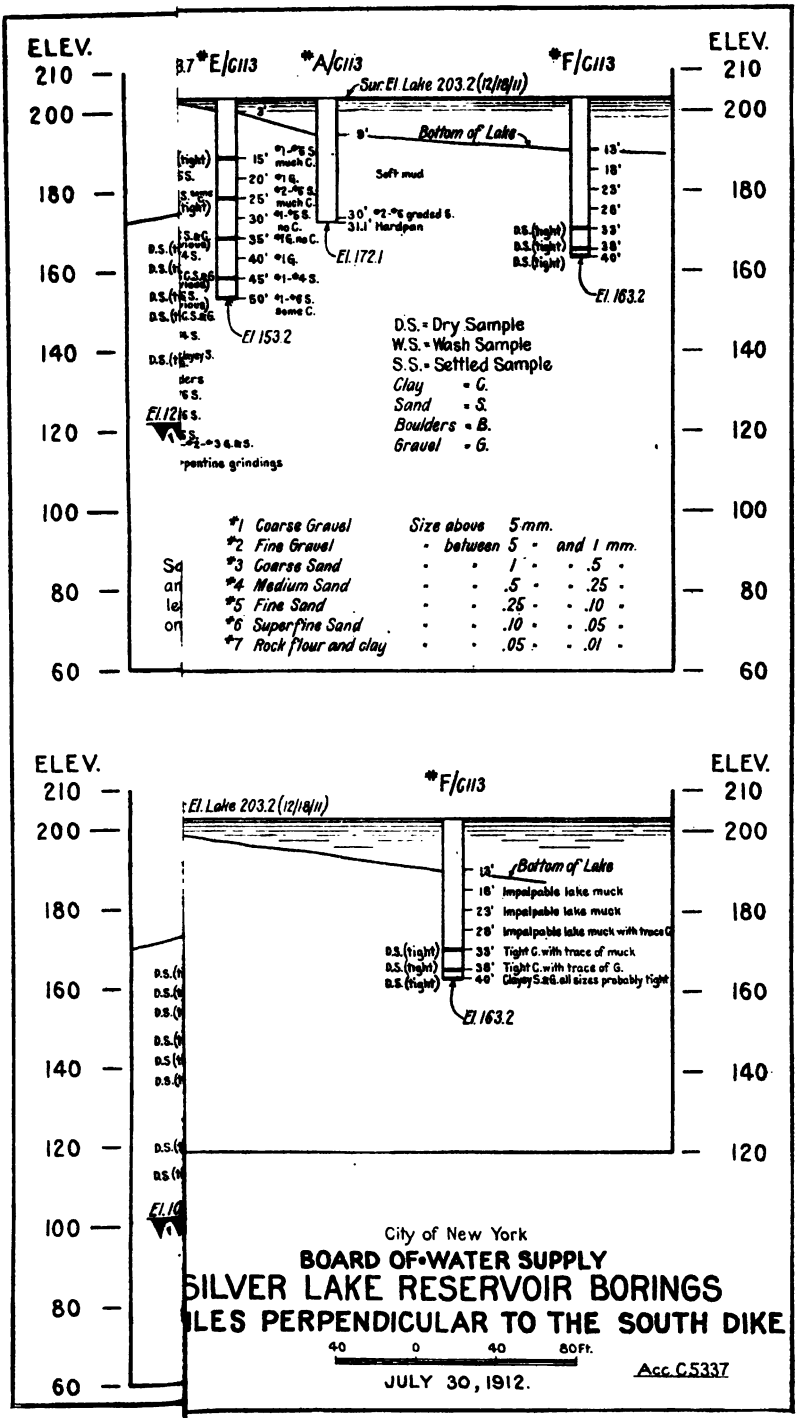
An abundance of mixed drift (" till ") is available for such work. It is probable that some places are more clayey than others and therefore better suited to such use. In all cases material in the immediate vicinity of the work is suitable for its construction. No better is likely to be obtained on the island.

Explorations

Borings into bed-rock have shown low core saving and in places a poor quality of rock. The serpentine as a whole is rather soft and much jointed and is easily ground up in the drilling process. But in this it does not differ from the rock as seen elsewhere in the vicinity.

Exploratory borings have been made on the sites of the proposed dikes and the data have been interpreted and plotted. The accompanying structural profiles (see Sheet 17) exhibit items furnished by this investigation that have a bearing on the questions under present discussion. It is evident at once, from an inspection of the borings, that the rock floor lies as much as 99 feet below the surface at the deepest notch where the south dike cuts across the outlet. But an interpretation of the samples saved during the progress of the work leads to the conclusion that the drift material as a whole is tight and of fairly good quality for the uses intended.

This diagram, showing the profile and borings data, is like-


ELEV.
210
200
180
160
140
120
100
80
60
*E/G113
*A/G113
*F/G113
Sur. El. Lake 203.2 (12/18/11)
Bottom of Lake
Soft mud
El. 172.1
El. 153.2
El. 163.2
D.S. = Dry Sample
W.S. = Wash Sample
S.S. = Settled Sample
Clay = C.
Sand = S.
Boulders = B.
Gravel = G.
*1 Coarse Gravel Size above 5 mm.
*2 Fine Gravel between 5 and 1 mm.
*3 Coarse Sand 1 .5
*4 Medium Sand .5 .25
*5 Fine Sand .25 .10
*6 Superfine Sand .10 .05
*7 Rock flour and clay .05 .01
Impalpable lake muck
Impalpable lake muck
Impalpable lake muck with trace G
Tight C. with trace of muck
Tight C. with trace of G.
Clayey S. & G. all sizes probably tight
City of New York
BOARD OF WATER SUPPLY
SILVER LAKE RESERVOIR BORINGS
LES PERPENDICULAR TO THE SOUTH DIKE
40 0 40 80 Ft.
JULY 30, 1912.
Acc. C.5337

wise an illustration of the most satisfactory method of taking and recording samples. It covers only the explorations on two lines crossing the site of the South dike, but this is typical local ground, and the drawing tabulates the most important items of geologic interpretation of the borings so fully that it may well take the place of a more extended discussion.

Summary

(a) There are only two formations to be considered at this reservoir site—The Staten Island serpentine and the glacial drift.

(b) The two basins are essentially impervious—both formations favoring this condition.

(c) Suitable material for dike construction is available on the immediate ground.

(d) Exploratory borings show reasonably good type of drift even to the deepest portions of the dike sites.

The geologic features on the whole are very favorable, and there seems to be every reason to expect additional explorations to further support this opinion.

ON THE QUESTION OF FEASIBILITY OF THE TUNNEL PLAN

Additional exploratory investigations have been made at some of the shaft sites and at the north end of Morningside park since the original reports, on which the above discussion is based, were written. Explorations were continued on the lower east side up to the time of the beginning of actual construction. Although considerable additional detail accumulated from these sources, there were no new features discovered and no new or unlooked for conditions disclosed of sufficient prominence to modify the descriptions and opinions, already formulated, further than to determine the extent and boundaries more closely.

The Lower East Side section has claimed special attention from the beginning and this is still kept up. Exploratory work is slow and much hampered by heavy drift cover. This fact, together with the difficulty of interpreting some of the materials secured from boring, led to a fairly general belief that the ground itself is especially poor for tunnel purposes. A

thorough study of all of the data, interpreted in a manner consistent with the known geologic characteristics and habit of the region, does not support such a view. Neither exploration nor construction, so far as it has progressed, have shown any condition that can be regarded as sufficiently questionable to make the tunnel plan of distribution conduit impracticable. On this point the opinion written March 22, 1910, the essential parts of which are given below, either in quotation or abstract, needs no revision.

The most important question involved in the outcome of these explorations is whether or not the bed-rock tunnel is feasible. Or are there known conditions which cannot be avoided that would make such construction unsafe or insecure? Or are the unknown portions or untested stretches of enough uncertainty to throw a reasonable doubt on the practicability of the enterprise?

Even preliminary studies and explorations show beyond question that nearly the whole line could be located within formations of constant character and known quality about the behavior of which there is no reasonable doubt. Only at a few places has it been advisable to pursue exploratory work in much detail. These places are:

(a) The Harlem river (167th street).
(b) Manhattanville cross valley (125th street).
(c) Morningside to Central park (106th and 110th streets).
(d) Lower east side (the Bowery and East river).
(e) East River crossing (Clinton street to Bridge street).

Whatever uncertainty or question there can be about the practicability of the tunnel plan must arise in connection with some of these points, all of which have been extensively explored.

At the Harlem river the geological conditions on the proposed line are proven to be essentially identical with those 2,000 feet further north where the New Croton tunnel is located. The crossing is therefore understood and, as already shown by this Croton tunnel, the rock tunnel plan is clearly practicable.

At the Manhattanville cross valley, between 123rd street and 127th street, thorough explorations show that Manhattan schist of normal type is continuous and that there is no very deep decay. The rock is of a type and quality that is well known in this City as suitable for large tunnels.

From Morningside to Central park the line finally selected extends southward on Columbus avenue to 106th street and thence eastward to Central park. Explorations show that a good grade of Manhattan schist exists wherever tested on this line. The borings were located at places judged to be most likely to show poor ground, but the results indicate that the weak ground has been avoided. No local conditions are known that throw any doubt on the feasibility of this portion of the line.

On the lower east side, on Delancey, Hester and Clinton streets, all of the local formations are crossed in a series of narrow belts that exhibit complicated structure. Proper interpretation of all data leads to the conclusion that the belt is of essentially the character and relation that one can find elsewhere and that was to be expected in some form here. Therefore it is understandable and the chief object of exploratory investigation has been accomplished. There are no new principles involved and no new conditions. The only feature directly affecting the question of practicability is that of depth of decay, and, as a consequence, the depth at which the tunnel should be placed.

This is shown now to be deeper than at any other place on the line, but it follows certain zones or belts that are comparatively narrow and that steadily become narrower and better with depth until finally, in all cases, good, firm rock is reached. There is no doubt whatever but that by far the greater portion of the line across this belt passes through perfectly good sound rock even at moderate depths. By placing the tunnel deeper, as has been done, the proportion of sound rock is increased so materially that the possible amount of weak ground becomes of little consequence as affecting the whole scheme.

At the East river, explorations have shown that the rock is in exceptionally good condition.

In summary, therefore, on the question of practicability the following opinion may be given.

The rock formations that will have to be penetrated all belong to well-known types in which tunneling is already extensively and successfully carried on. The only sources of difficulty are connected with special local rock conditions where

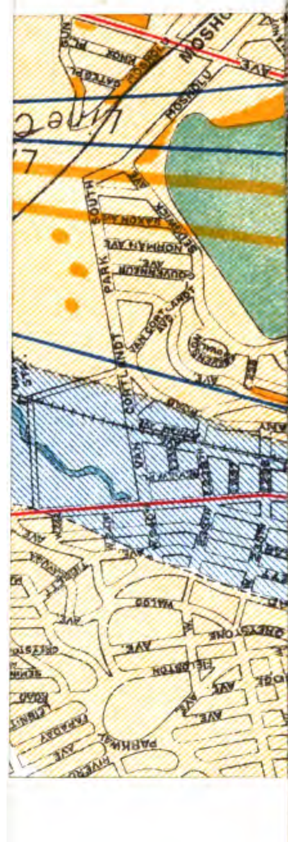
there is crushing and decay. These conditions characterize certain zones of determinable field relations—chiefly faults and contacts. Sometimes such zones can be avoided by locating to one side parallel to them. This is the method used in long stretches where the original trial lines were shifted. If such zones have to be crossed there are still two ways of avoiding the chief dangers of them. One takes advantage of the fact that all structures tend to die out sooner or later along the strike and therefore it is sometimes possible to go around the end out of reach of the worst effects. This is the way adopted in passing from Morningside to Central park accomplished by shifting the line from 110th to 106th streets. The other way is to go deep enough with the tunnel to get below the worst effects of decay. This is the only way possible where a series of persistent weak zones have to be crossed, and it is necessarily the method employed through the lower east side.

A review of all data and consideration of th established geologic characteristics of the locality, after making allowances for every factor that can by any possibility modify present evidence, has convinced those who have faced this responsibility that the tunnel plan of conduit construction is entirely feasible throughout the whole distance from Hill View reservoir to Brooklyn.

Yours very truly,

CHARLES P. BERKEY,

Geologist.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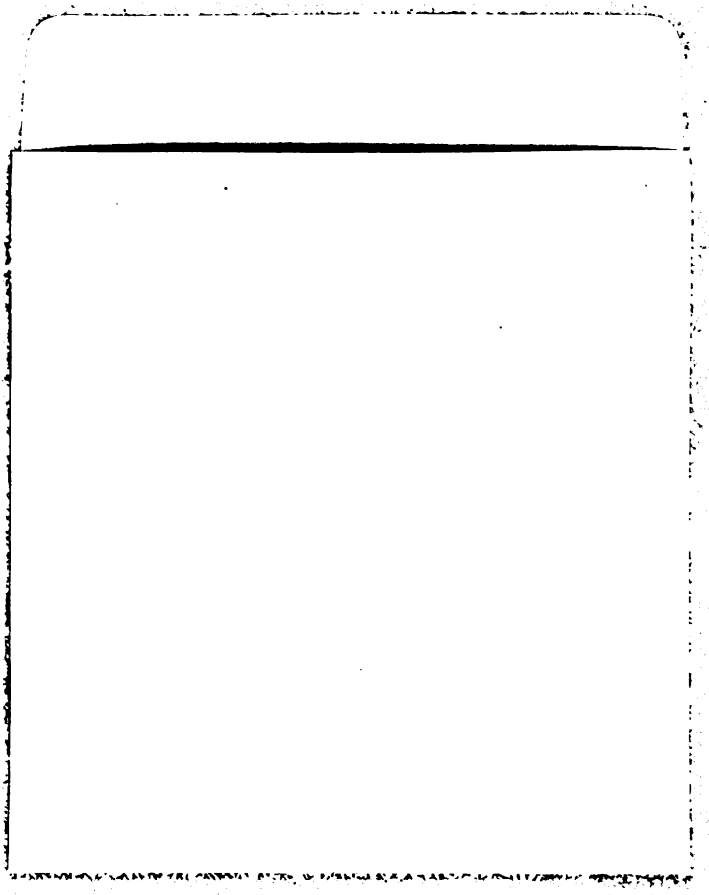

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